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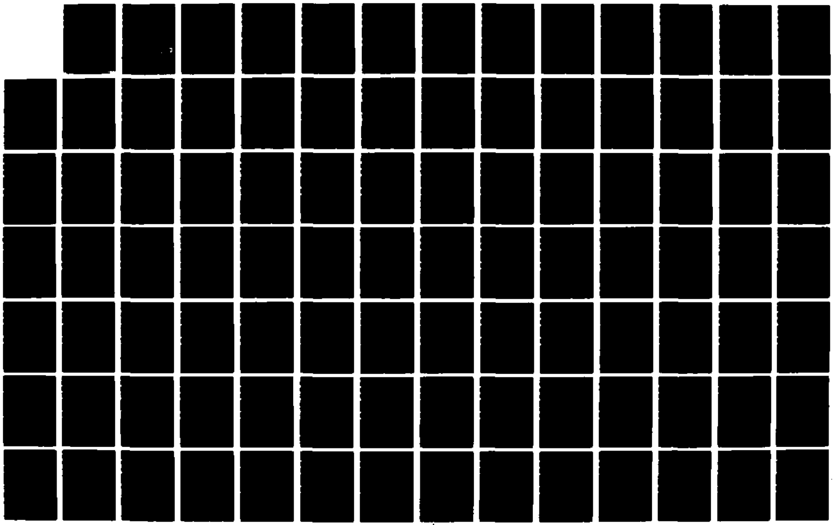

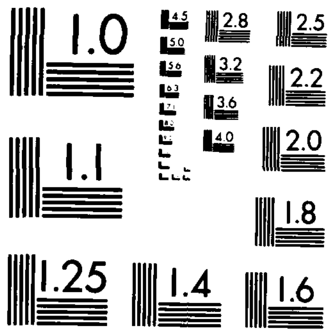

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WATER DISTRIBUTION ANALYSIS AND OPTIMIZATION (WADISO)

USER'S GUIDE AND DOCUMENTATION

by

Johannes Gessler, John W. Sjostrom, Thomas M. Walski

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This document provides guidance on the use of a computer program WADISO (Water Distribution System Analysis and Optimization). The model consists of three major parts: steady state simulation, optimization, and extended period simulation. The steady state simulation portion computes flows and pressures in pipe networks under steady state conditions. The optimization portion optimally sizes pipes in a water distribution system and selects optimal pipes for cleaning and lining. The extended period simulation or time simulation computes pressure and flow distribution in pipe networks taking into consideration fluctuating tank water levels and varying water use patterns over time.

All parts of the program can handle virtually any typical water distribution system and allow for the presence of pumps, pressure reducing valves, check valves, and multiple supply points. The program accepts input interactively from the terminal via keywords.

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There are no limitations to the layout of the system except that there must be at least one tank or reservoir for each network. The optimization part of the program is intended to be used in the sizing of a limited number of pipes. Typically this part of the program is used to size the pipes in an expansion of an existing system, or to improve the pressure conditions in an existing conditions by reinforcing the system through the cleaning of selected pipes or the addition of pipes parallel to existing pipes. In addition to varying tank water levels and water use patterns, the extended period simulation allows for fire flows, pumps controlled by tank water level and time, and pipes opened or closed during different times during a simulation.

The document is divided into two parts. Part 1 provides guidance on the use of the WADISO computer model and Part 2 provides detailed documentation of the program. Appendices to Part 1 describe how to access the program on the CDC Cybernet Computer System, run the program on the CDC Cybernet and personal computers, and use different data files while running the program.

PREFACE

The computer program described in this chapter was developed under the MAPS (Methodology for Areawide Planning Studies) Work Unit under the Water Supply and Conservation Research Program. The technical monitors for the program at the Office of the Chief of Engineers were Mr. Jim Baliff (CEEC-BU) and Mr. Robert Daniel (CECW-PD).

The work was performed in the Water Resources Engineering Group (WREG), Environmental Engineering Division (EED), Environmental Lab (EL), at the US Army Engineer Waterways Experiment Station (WES) in Vicksburg, Miss. Dr. Johannes Gessler, Civil Engineering Department of Colorado State University, developed the program with assistance from Mr. John W. Sjostrom, WREG, and Dr. Thomas M. Walski, WREG. The report was reviewed by Dr. James Male, Environmental Engineering Department of University of Massachusetts and Mr. John Cullinane of the Water Supply and Waste Treatment Group (WSWTG), EED, EL, WES.

The program development was conducted under the direct supervision of Dr. F. Douglas Shields, Acting Chief, WREG, and under the general supervision of Dr. Raymond L. Montgomery, Chief EED; and Dr. John Harrison, Chief, EL.

During the preparation of this report, COL Allen F. Grum and COL Dwayne G. Lee were the Commanders and Directors of WES and Dr. Robert Whalin was Technical Director.

Background and Purpose

1. WADISO (Water Distribution Analysis and Optimization) is a computer program which models water distribution systems. The main purpose of the program is to assist engineers in designing least-cost improvements to water systems to meet performance standards.

2. This report is part of the Methodology for Areawide Planning Studies (MAPS) manual, which is Engineer Manual EM 1110-2-502. This report was issued as Chapter 28 (Change 6) to the MAPS manual. There are two parts to the report.

3. Part 1 of the report provides guidance on the use of the WADISO computer model. Appendix A to Part 1 describes how to access the program on the CDC Cybernet Computer System and run the program on the CDC Cybernet computer using different data files. Appendix B to Part 1 describes the required hardware and software for running the IBM PC or compatible version of the program and how to run the program on the IBM PC using different data files.

4. Part 2 of the report provides detailed documentation of the WADISO program. This part discusses the internal workings of the program in terms of how the program accepts input data and stores data and how the program performs calculations. Descriptions of subroutines and variables are also provided as well as the hierarchy of subroutines in the program.

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CHAPTER 28

WATER DISTRIBUTION SYSTEM ANALYSIS AND OPTIMIZATION

Section 1. Introduction

28-1. Purpose. This MAPS (Methodology for Areawide Planning Studies) chapter provides guidance on the use of the WADISO (Water Distribution System Analysis and Optimization) computer module for the MAPS program. WADISO is a user-friendly computer program that aids the engineer in determining optimum pipe sizes for use in studies and for constructing, reinforcing, expanding, and rehabilitating water distribution systems.

28-2. Scope of Chapter. WADISO has been developed at the US Army Engineer Waterways Experiment Station (WES) for the Office, Chief of Engineers. This chapter explains how to use the module and interpret the results. It assumes that the user is familiar with the basic principles of flow in pipe networks as they apply to the computation of flow and pressure distribution. In Part 2 of this manual, Documentation, a description of the program code is provided. Knowledge of computer programming is not required to read the User's Guide or to use the program. However, appreciation of the Documentation requires programming experience. Features of the program are described in the remainder of Section 1; program control for simulation is described in Sections 2 and 3; program control for optimization is described in Section 4; running the optimization is described in Section 5; and running the extended period simulation, in Section 6. Section 7 defines the error messages displayed by the program.

28-3. WADISO and MAPS. Although WADISO was developed under the MAPS work unit of the Water Supply and Conservation Research Program, it is a stand-alone program. Instructions for accessing the program on the CDC Cybernet computer are provided in Appendix B of this manual. Running the program on the IBM PC is discussed in Appendix C. Instructions on obtaining the WADISO program and documentation are given in Appendix D.

28-4. Description of WADISO. The WADISO module consists of three major parts. The first part (simulation routine) computes pressure and flow distribution in pipe networks. The second part (optimization routine) calculates cost and pressure distribution for a set of user-selected pipe sizes and changes the sizes for selected pipes within user-specified limits until it finds the most economical arrangement that meets the pressure requirement. The third part (extended period simulation) computes pressures and flow distribution in pipe networks taking into consideration fluctuating tank water levels and varying water use patterns over time. All parts allow for the presence of pumps, pressure-reducing valves, and check valves within the water distribution system, as well as multiple supply points. There are no limitations to layout of the system except that there must be at least one constant head node (tank or reservoir) for each network. The optimization part of the program is intended for use in sizing a limited number of pipes. Typically,

this part of the program is used to size pipes in an expansion of an existing system, or to improve the pressure conditions in an existing system by cleaning selected pipes or adding pipes parallel to existing pipes. The program is not intended for the sizing of all pipes in large systems. Such sizing is possible with the employed methodology, but the computer time required for the optimization would be prohibitive.

28-5. Features of WADISO. While WADISO is a very complex computer program, it is designed such that it is easy to use. Those users familiar with the MAPS computer program will find a considerable amount of similarity between the two programs. Nevertheless, there are differences, and the user should not automatically assume the WADISO program always works the same as the MAPS program.

a. Computer Experience. No prior experience with computer programming is required in order to use WADISO. All of the commands used during program operation are explained in this manual. System commands required to manage data files on the CDC Cybernet system are described in Appendix B, and commands to run WADISO on the IBM PC are found in Appendix C.

b. Interactive Use of the Program. The WADISO program is designed to be used in an interactive mode. Prompts will appear at the terminal to guide the user through the program. If the program detects an error or inconsistency, it will print a warning. (See Section 7 for error message descriptions.) Output is provided immediately after each run. If the user wishes, it is possible to run WADISO in batch mode. This allows the user to take advantage of lower computer cost for batch mode processing when using the CDC Cybernet system.

c. Modular Structure. The program can be run in three ways: as a steady-state simulation, as an optimization, or as an extended period simulation routine. For steady-state simulation the user does not need to enter data for cost and optimization constraints related to the optimization routine. Time data related to the extended period simulation are not necessary for the steady-state simulation routine either.

d. Data Files. Simulation and optimization of water distribution systems require a considerable amount of data. Data for the simulation portion of the program can be stored from one run to the next in user-specified files. Additional files can be used to store optimization data and cost data. The files are built while using the program. Additional information involving files is found in Appendix B for the CDC Cybernet computer and Appendix C for the IBM PC.

28-6. Status of WADISO. This manual reflects the status of WADISO as of 1 March 1987. However, it is the intent to continuously revise and update the program to meet the needs of the users. A potential user should check with the program developers at WES, commercial number 601-634-3931 or FTS 542-3931 to determine whether any revisions have been issued since this version of the manual was prepared.

Section 2. Program Control of Simulation Routine

28-7. Introduction. Program execution is controlled from six menus using an interactive format. One menu controls access to the four major routines of the program: simulation, optimization, cost data entry, and time simulation. Two menus control the steady-state simulation routine, and one menu each controls the cost data, optimization, and time simulation routines. Figures 28-1 through 28-3 show the overall layout of the program. Figure 28-1 emphasizes the program steps involving steady-state simulation, while Figure 28-2 emphasizes optimization and Figure 28-3 emphasizes the extended period simulation.

28-8. Program Start-Up. After starting the program, the user sees the following menu:

```
PROGRAM CONTROL:

    SIMULATION        :  ENTER 1  PRESS RETURN
    OPTIMIZATION      :        2
    COST DATA         :        3
    TIME SIMULATION   :        4
    TERMINATE PROGRAM :        9
```

a. Printing of Menus, Prompts, Responses. The interactive mode of the program automatically prints menus and prompts and does not echo user's responses. If the user desires a different operation (e.g., for running the program in the batch mode), he may effect printing of menus, prompts, and user's responses by entering any of the responses shown in Table 28-1. After keying in any of these responses, the program returns to the program control menu.

b. Simulation. To enter the simulation routine, the user selects option 1. In the menu which follows, the user can select between two options. Option 1 will permit the user to enter a new system. Option 2 lets the user retrieve the data from a local file containing data of a system previously entered and stored:

```
SIMULATION ROUTINE

    SELECT PROGRAM OPTION :

      TO ENTER NEW SYSTEM :  ENTER  1  PRESS RETURN
      TO RETRIEVE DATA    :         2
```

If option 1 is selected, the program will start to request data (see paragraph 28-13, Data Input). If option 2 is selected, the program will request the file name (see paragraph 28-17, Storing Data).

28-9. Option Menu. The main option menu is accessed after an option previously selected is completed (i.e., when a new system has been entered and the

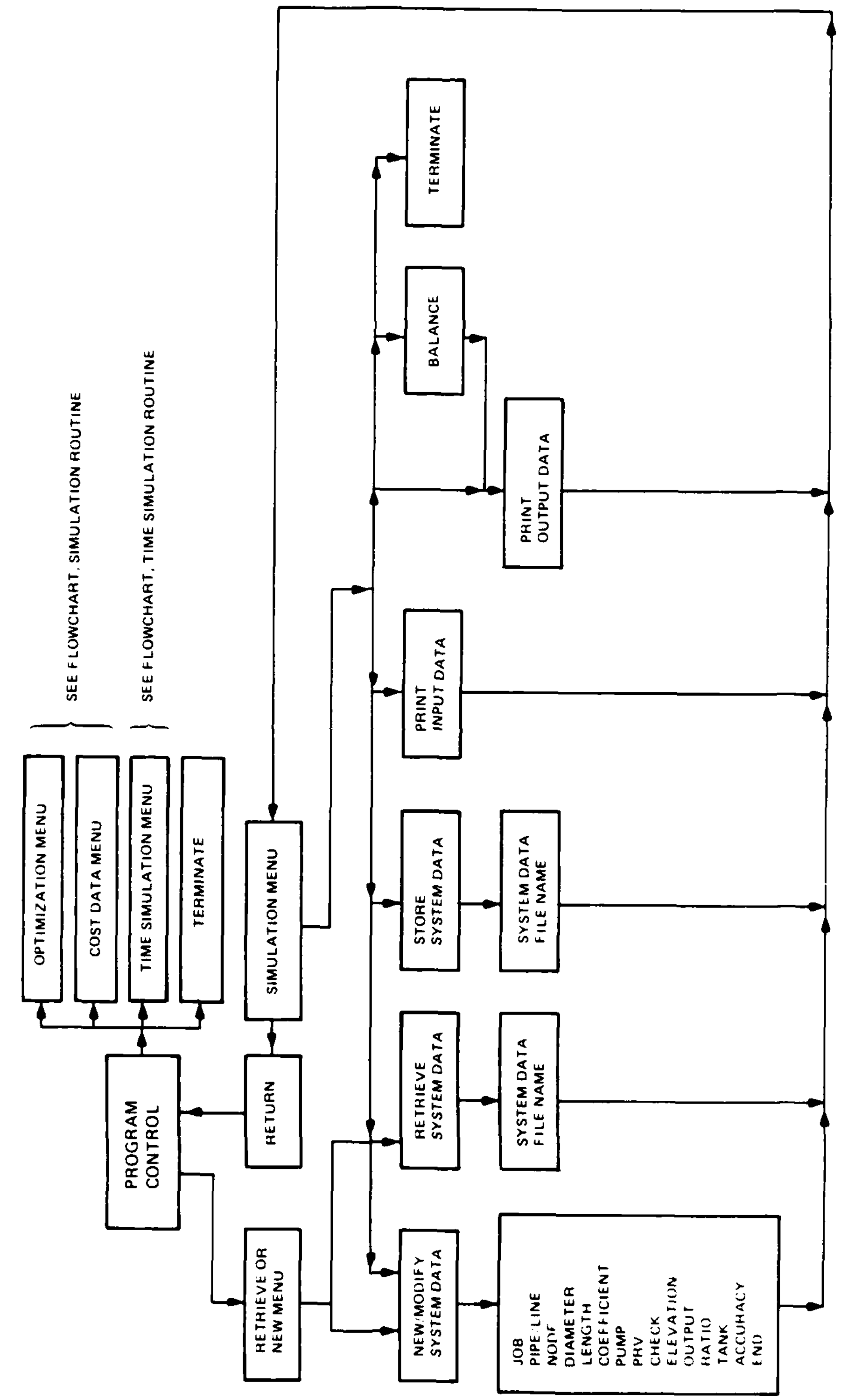

Figure 28-1. Flowchart, simulation routine

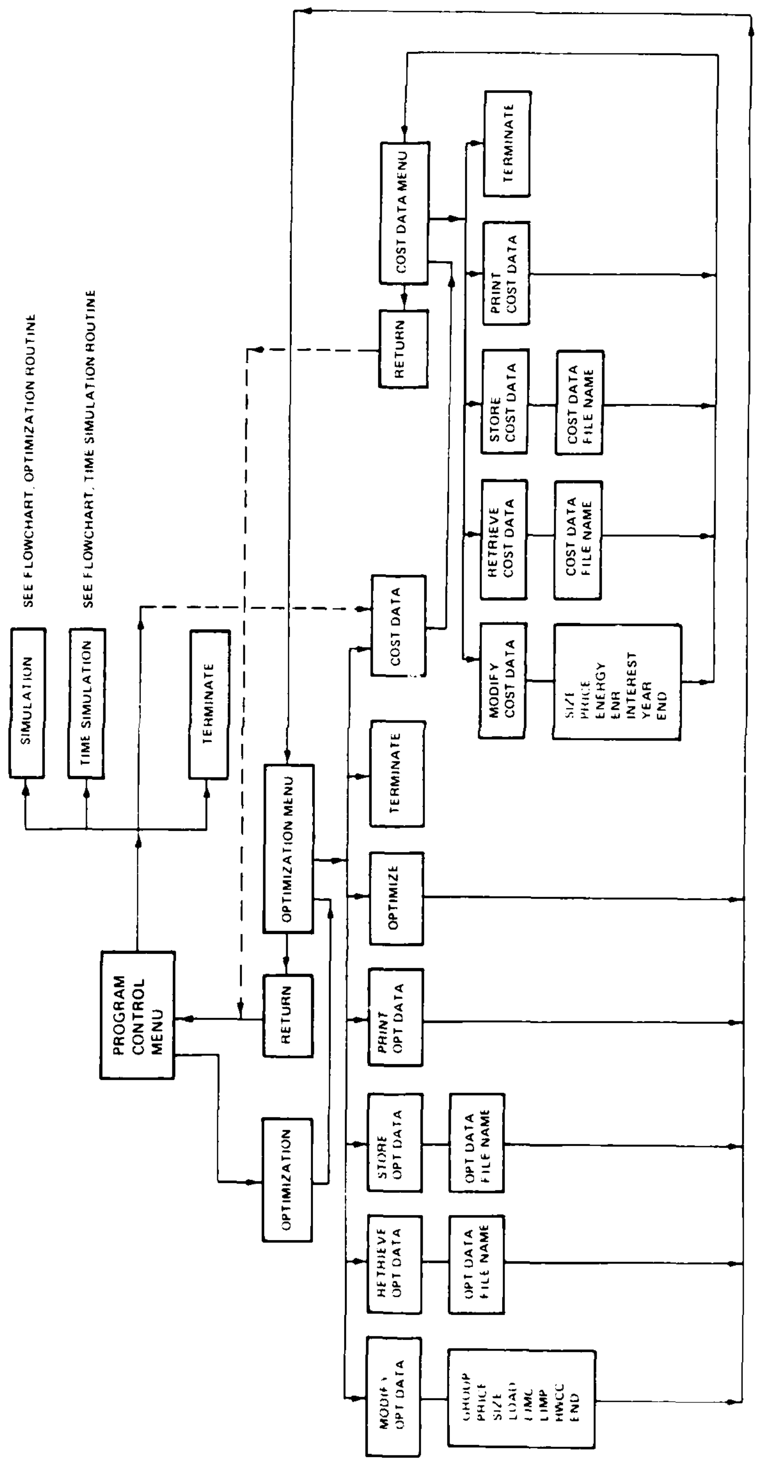

Figure 28-2. Flowchart, optimization routine

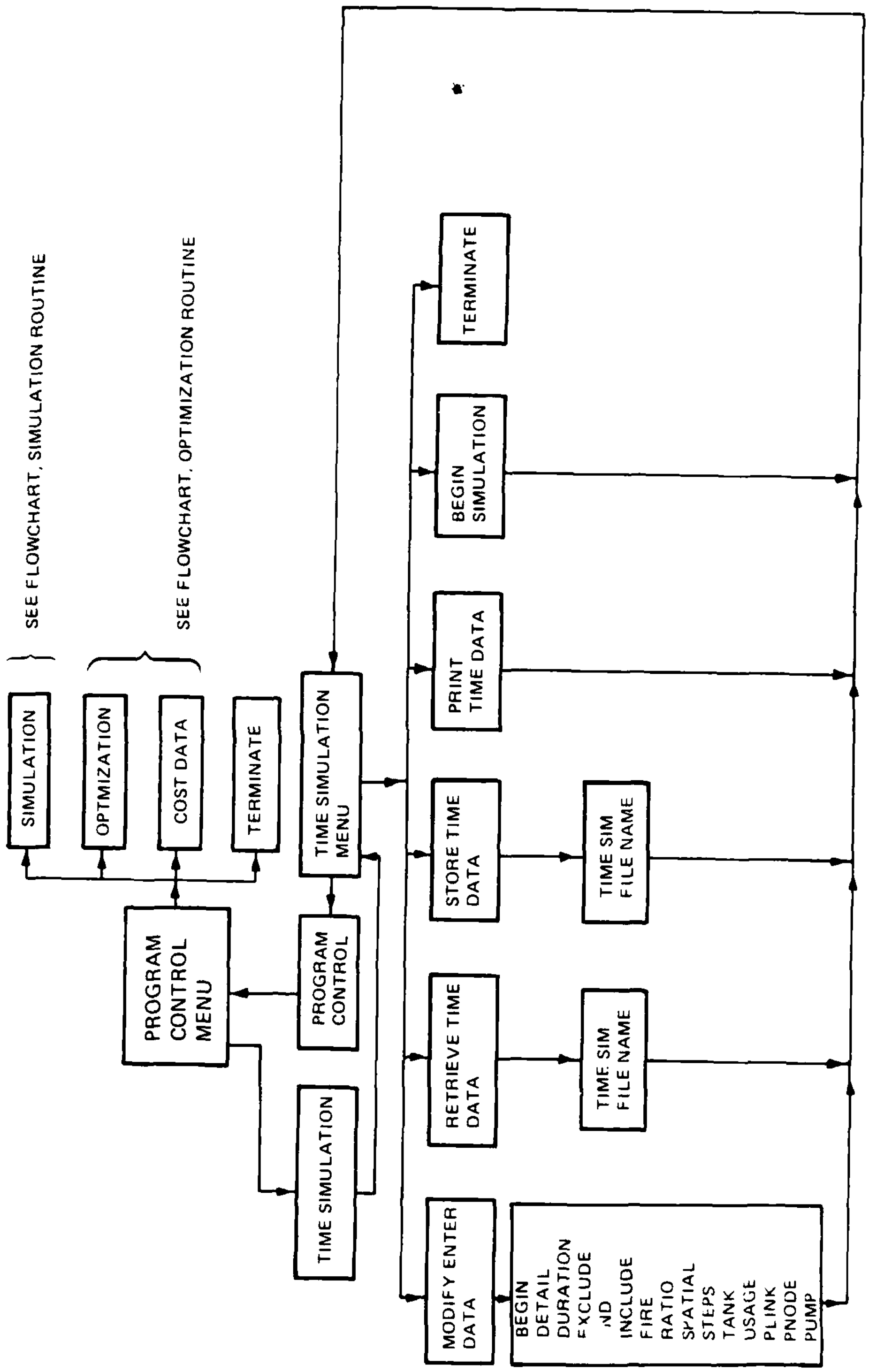

Figure 28-3. Flowchart, time simulation routine

Table 28-1. Character Responses to Program Control Menu and Their Results

RESPONSE	RESULT
EC	User's responses are echoed.
ME	Menus are printed.
MEN	Menus and prompts are printed. User responses are not echoed. (Default)
NE	User responses are not echoed.
NM	Menus are not printed.
NOM	Menus and prompts are not printed. User's responses are echoed.
NP	Prompts are not printed.
PR	Prompts are printed.

user has typed END or an old system has been retrieved). The menu allows the user to select several options: balancing the network (calculation of flow and pressure distribution), modifying the network (including change of individual parameters, expansion of system, or deletion of part of the system), printing the input data, storing the data under a user-selected file name, retrieving data from a file in which the data were previously stored, printing the output (this option is available only if the system was previously balanced), returning to the program control menu, and terminating the program. The option menu as displayed at the terminal is reproduced below.

```
SELECT PROGRAM OPTION:

   BALANCE           :  ENTER  0 OR OC  PRESS RETURN
   MODIFY SYSTEM     :         1
   PRINT INPUT       :         2    2C
   STORE DATA        :         3
   RETRIEVE DATA     :         4
   PRINT OUTPUT      :         6    6C
   PROGRAM CONTROL   :         8
   TERMINATE PROGRAM :         9
```

The options with a C behind the number refer to the format in which input or output is to be printed. Without the C the program will pause after the printing of one screen (input) or one page (output). This is used for reviewing the input data and the output data on a CRT terminal. The option with a C (for Continuous) is used for producing a hard copy at a printer (i.e., no stopping after the printing of each page). If the user is viewing data one

page at a time, the program pauses after printing one page. The user enters any character (except C and E) to view the next page. If the user enters a C, the program will switch to continuous output. If the user enters an E (for Exit) during the printing of the node table, the program will advance immediately to the top of the pipe table. If E is entered during the printing of the pipe table, printing is terminated. Since option 0 automatically accesses option 6 (i.e., output is always printed after balancing), this convention also applies to option 0. After an option is completed, program control returns to the main menu, except for option 9.

28-10. Description of Options. A general description of each of the options displayed in the menu follows.

a. BALANCE. Under this option the program calculates the pressure and flow distribution in the water distribution system and prints the results.

b. MODIFY SYSTEM. This option allows the user to return to the data input routine where any system parameter can be changed, or a system can be expanded, or part of a system can be deleted.

c. PRINT INPUT. This option permits the user to view the data that were entered or modified in the input routine.

d. STORE DATA. To store data in a local file, the user must access the store routine. The program does not store the data automatically after each run.

e. RETRIEVE DATA. This option enables the user to retrieve data that were stored under d. above. The data must be in a local file. This option is equivalent to option 2 at the time of program start-up (see paragraph 28-8).

f. PRINT OUTPUT. This option is available only if the system is balanced. It will print two tables, one for the node data and one for the link data. This option is automatically accessed after balancing a system (see a. above).

g. PROGRAM CONTROL. This option enables the user to return to the program control menu. If a pipe network is to be optimized (sizing of a set of user-selected pipes) or modeled for extended period simulation, the user must return to the program control menu before either of these routines can be accessed.

h. TERMINATE PROGRAM. This option will terminate the computer run.

Section 3. Steady-State Simulation of Distribution Systems

28-11. Introduction. The water distribution system analysis part of the program calculates the level of the energy grade line and pressure at each node, the flows and head losses in each pipe, flow and head for each pump, and mode of operation for each pressure reducing valve (PRV) and check valve for steady-state conditions. The program works for looped and branched networks.

There is no need for the user to identify loops in the network. The program can be run as a stand-alone program and is required with the optimization routine and the extended period simulation routine.

28-12. Definition of Terms. Throughout this chapter a number of terms are used which may appear to be standard in connection with water distribution system analysis. Yet their precise definition may be important in the context of WADISO and this section on water distribution systems.

a. Pipe Network. While this term is used interchangeably with water distribution system, a pipe network consists of links and nodes and refers more to the mathematical representation of a water distribution system.

b. Link. Links are elements that connect two nodes. A link can be a pipe (with or without a check valve), a pump, or a PRV. A link is defined by its link number and the numbers of the two nodes it connects.

c. Node. Nodes are the end points of links. One or more links connect a node to the network. Supply points (reservoirs, tanks) are also nodes since they are end points of links. Each node is identified by a number.

d. Pipe. A pipe is a link. It is assumed to have a constant diameter between the two nodes it connects. The diameter is expressed in inches, and the length is expressed in feet. The program uses the Hazen-Williams head loss equation and the corresponding Hazen-Williams coefficient. The term "line" is equivalent to "pipe."

e. Pump. A pump is a link. It has a characteristic curve that defines the relationship between pump discharge (in gallons per minute) and pump head (in feet). The user specifies three points on the characteristic curve. The program will then fit a parabola through the three points. The constant term of the parabola must be positive. The first derivative at zero flow must be negative, and the second derivative must be negative (see Figure 28-4). As an option the user can enter only one point on the curve (e.g., the rated capacity and head). In this case the program will default to a characteristic curve, described in paragraph 28-13.l and shown in Figure 28-4. A pump link has no length associated with it. Elevations of the beginning and ending nodes of the pump link should be the same.

f. Pressure Reducing Valve. A PRV is another type of link. The pressure setting (in pounds per square inch) for a PRV is the pressure the valve will try to maintain on the downstream side of the PRV. If the downstream pressure can be maintained at the pressure setting, the valve is ACTIVE. If for some reason the downstream pressure exceeds the valve setting, the valve is CLOSED. If the upstream pressure is less than the pressure setting, the valve is completely OPEN. The PRVs also act as check valves (i.e., reversed flow is not possible). In this case the valve is CLOSED. The operational mode of the PRVs (ACTIVE, CLOSED, or OPEN) is indicated in the program output. A PRV link has no length associated with it. Elevations of the beginning and ending nodes of the PRV link should be the same. Two PRVs cannot have the same ending node. The ending node of a PRV cannot be the beginning node of

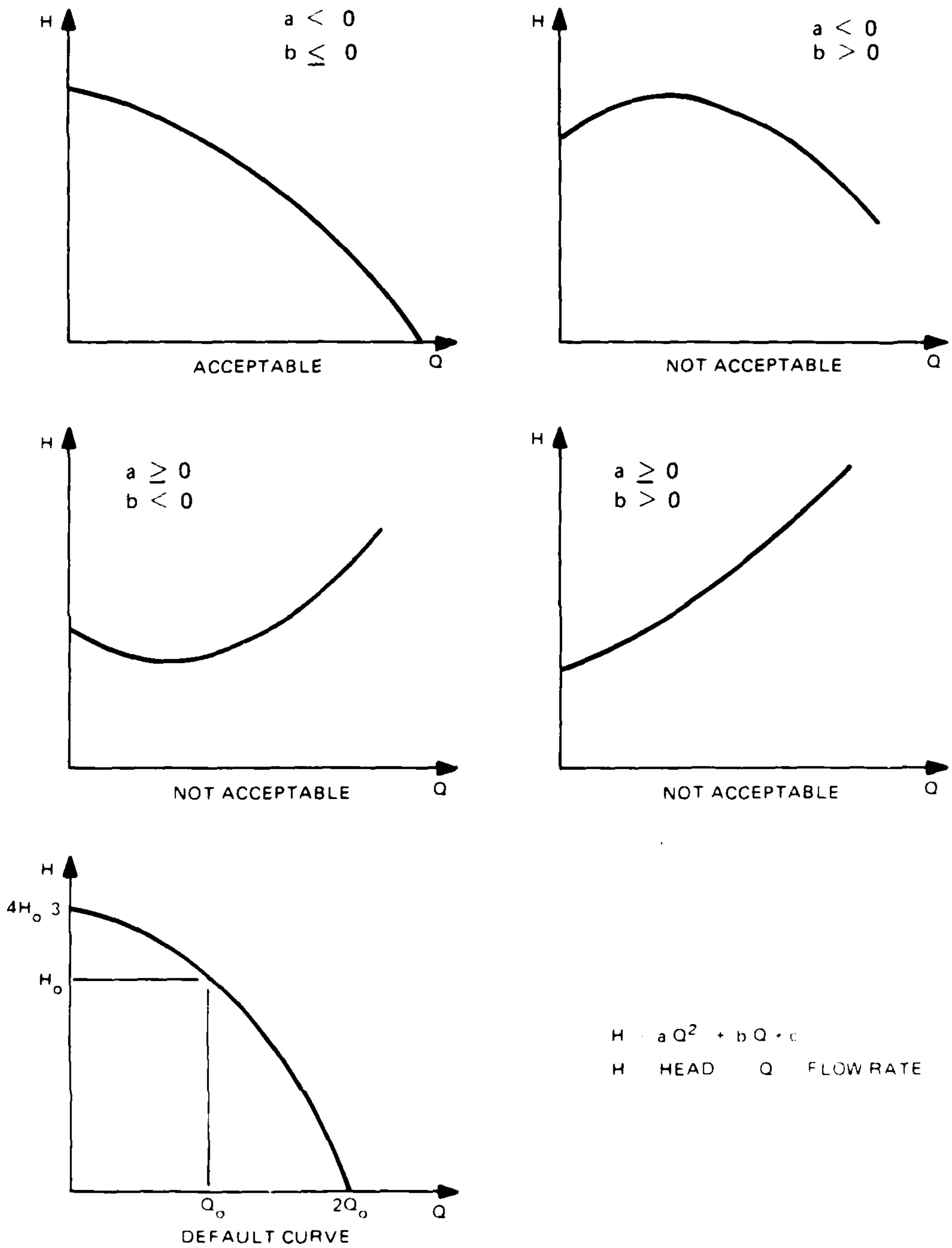

Figure 28-4. Acceptable, unacceptable, and default pump curves

another PRV. In these cases the two PRVs must be separated by at least one leg of pipe, no matter how short.

g. Check Valve. A check valve limits the flow direction in a pipe. A check valve is always associated with a pipe and is therefore not a link by itself. If the check valve is open, the output will show the standard pipe information, followed by the letters CV (for check valve). If the check valve is closed, the word CLOSED is printed in the output instead of the flow data.

h. Reservoir. A reservoir is a node with a fixed water level (hydraulic grade line). The elevation of the node is designated as the elevation of the free water surface; that is, the node elevation (in feet) and elevation of the water surface coincide. The pressure at such a node is zero.

i. Tank. A tank is a node with a fixed water level (hydraulic grade line). The node elevation (in feet) is the elevation of the foot of the tank. The tank water level indicates the vertical distance from the foot of the tank to the free surface. Unlike a reservoir, tank node shows a pressure larger than zero. The net inflow from, or outflow to, the tank is computed by the program; therefore, it cannot be assigned a flow input or flow output. Although the program is not constrained so, it is easy to think of a reservoir as a water supply reservoir and a tank as an elevated storage (distribution) tank.

j. Output. Output refers to the amount of water (in gallons per minute) that is withdrawn from the system at a node. Domestic or industrial usage and fire flows are examples of output. Output is treated to be independent of local pressure. Output is the same as negative input. A node with output cannot be assigned a constant head.

k. Input. Input refers to the amount of water (in gallons per minute) that is forced into the system at a node. Input is treated to be independent of local pressure. Input is the same as negative output. A node with input cannot be assigned a constant head.

28-13. Data Input. Data for the distribution system analysis are entered interactively from the terminal. The keywords used during data entry are summarized in Table 28-2 and are described in detail below. There is some redundancy in the functions of the keywords, allowing the user flexibility. Some of the keywords are most useful for data input, while others are best used for modifications. Data are requested with the following prompt:

```
S. KEYWORD IS xxxx  ENTER (KEYWORD)  DATA LIST
```

The S. indicates that the user is in the simulation routine. At xxxx appears the current default keyword. For example, when the program expects pipe input, it would prompt S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST. The format of the user's input is then

```
Keyword  value1  value2...valuen
```

Table 28-2. Keywords for Water Distribution Simulation
(S. prompt)

ACCURACY	xx.x	xx.x	(xx)			
	Press. Accur.	Flow Accur.	Max. Number of Inter.			
CHECK VALVE	xxx	xxx	xxx			
	Link #	Node #	Node #			
COEFFICIENT	xxx	xxx	xxx.x			
	First Link #	Last Link #	Coef.			
or						
COEFFICIENT	xxx	xxx.x				
	Link #	Coef.				
or						
COEFFICIENT	xxx.x					
	Coef.					
CREA	(xxxx)					
	Data file name					
DIAMETER	xxx	xx.x				
	Link #	Diam. in.				
END						
ELEVATION	xxx	xxx.x				
	Node #	Elev. ft.				
GET	(xxxx)					
	Data file name					
INPUT	xxx	xxx.x				
	Node #	Input gpm.				
JOB	text					
LENGTH	xxx	xxxx.x				
	Link #	Length ft.				
LINE	xxx	xxx	xxx	xx.x	xxxx.x	(xxx.x)
	Link #	Node #	Node #	Diam. in.	Length ft.	Coef.
NODE						
	followed by prompt:	FOR NODE xx ENTER	ELEVATION OUTPUT			
	response:	xxxx.x	(xxx.x)			
		Elev. ft.	Output gpm.			
OUTPUT	xxx	xxx.x				
	Node #	Output gpm.				
PIPE	xxx	xxx	xxx	xx.x	xxxx.x	(xxx.x)
	Link #	Node #	Node #	Diam. in.	Length ft.	Coef.
PRV	xxx	xxx	xxx			
	Link #	Node #	Node #			
	followed by prompt:	ENTER PRESSURE SETTING				
	response:	xx.x				
		Press.Setting psi.				

Note: Values in parentheses indicate optional entry.

(Continued)

Table 28-2. (Concluded)

PUMP	xxx Link #	xxx Node #	xxx Node #
	followed by prompt: POINT x ON CHARACTERISTIC CURVE: ENTER DISCHARGE, HEAD		
	response: xxx.x Discharge gpm. xxx.x Head ft.		
	or: E for point 2 (default curve)		
RATIO	xxx First Node #	xxx Last Node #	x.xx Ratio
or			
RATIO	x.xx Ratio		
TANK	xxx Node #	xxx.x Tank Height ft.	

For example, to change the diameter of pipe 101 to 10 in., the user enters

DIAMETER 101 10.0

If data are entered without a keyword, the current keyword as displayed in the prompt ("PIPE" in the above example) will be used, and will remain unchanged. If a different keyword is to be entered, it must be included and will override the previous one. Under certain conditions the keyword may default to a new keyword. For instance, after the keyword JOB, the keyword defaults to PIPE. Or after the program detects an unrecognizable keyword, the keyword will default to PIPE. All the keywords can be abbreviated with the first four letters. Numeric values behind the keyword can be separated by blanks or by commas. There must be a space or comma between the keyword and the first numeric value. An entry of only the keyword followed by no numeric value displays the correct format(s) for keyword.

a. JOB. The alphanumeric characters entered after this keyword become the title of the job. It is printed at the top of every page of output. The length of the job name is limited to 60 characters.

b. PIPE. This keyword is used to enter the data for a pipe. Diameter is in inches; length is in feet. The format for this keyword is given below.

	Line #	Node #	Node #	Diameter (in.)	Length (ft)	Hazen-Williams Coefficient
PIPE	121	160	165	6.0	3756.0	120

Remember that the keyword need not be entered if the present keyword is PIPE. The numeric values can be separated by blanks or commas. The Hazen-Williams coefficient is optional. The program defaults to a value of 100, unless the default value is changed with the keyword COEF (see paragraph 28-13j). The order of the node numbers connected by a pipe does not matter. If the user

attempts to reenter a pipe, line, pump, or PRV that was previously entered, the program issues the message

```
ELEMENT xxx WAS PREVIOUSLY ENTERED FROM x TO x
NEW DATA RETAINED
```

where xxx is current link, pump, or PRV number and x's are node numbers of the link.

The link is modified with the new data.

c. LINE. This keyword is equivalent to the keyword PIPE.

d. ELEVATION. This keyword is used to enter the elevation of the nodes. It is the elevation at which the pressure of a node is to be determined. Elevation is given in feet and must be greater than zero. The format for this keyword is given below.

	Node #	Elevation (ft)
ELEVATION	115	867.6

Elevations also can be entered when using the keyword NODE (see paragraph 28-13o).

e. OUTPUT. This keyword is used to enter a constant output of water, for instance a domestic load, which is independent of pressure to be calculated by the program. Output is entered in gallons per minute. The format for this keyword is given below.

	Node #	Output (gpm)
OUTPUT	271	535.0

If output is assigned to a node previously declared a constant head node (with the keyword TANK), the output assignment overrides the constant head assignment. (A node cannot be both a constant output node and a constant head (tank) node.) Output also can be entered when using the keyword NODE (see paragraph 28-13o). Later, if the user attempts to redefine an input or output node as a tank, the program displays

```
x WAS ENTERED WITH OUTPUT/INPUT
NEW DATA RETAINED
```

where x is the node number.

The node becomes a tank.

f. INPUT. This keyword is used to enter a constant input of water into the system, which is independent of pressure to be calculated by the program. Input is entered in gallons per minute. The format is the same as for output.

	Node #	Input (gpm)
INPUT	317	525.0

Using the INPUT keyword is equivalent to using the OUTPUT keyword with a negative value for the output. If input is assigned to a node previously declared a constant head node (with the keyword TANK), the input assignment overrides the constant head assignment.

g. TANK. This keyword is used to designate a node with constant head. The format for this keyword is given below.

	Node #	Tank Water Surface Height (ft)
TANK	7	85

The water level in the tank is given in feet above the elevation of the node. If a tank water level of zero is specified, the program will label the node as reservoir. If a tank is assigned to a node previously declared a node with input or output (with the keyword INPUT or OUTPUT), the tank assignment will override the input or output assignment. If the user later attempts to enter an input or output for a node that was previously entered as a tank, the program responds

```
x  WAS ENTERED AS A SUPPLY POINT
NEW DATA RETAINED
```

where x is the node number.

The node becomes an input or output node.

h. DIAMETER. This keyword is used to indicate the diameter of a pipe. Diameter is given in inches. The format for this keyword is given below.

	Link #	Diameter (in.)
DIAMETER	17	8.0

This keyword is typically used only when changing a diameter, since usually the diameter is specified under the keyword PIPE. If a user attempts to enter a diameter for a pipe not yet entered under the keyword PIPE, the program will print an error message. If the pipe size is to be determined during the optimization, any pipe size can be entered for diameter.

i. LENGTH. This keyword is used to enter the length of a pipe. Length is given in feet. The format for this keyword is given below.

	Link #	Length (ft)
LENGTH	38	5260.0

This keyword is typically used only when changing a length, since usually the length is specified under the keyword PIPE. If the user attempts to enter a length for a pipe not yet entered under the keyword PIPE, the program will print an error message.

j. COEFFICIENT. This keyword is used to enter the Hazen-Williams coefficient of a pipe or group of pipes, or to change the default value. Which one of these three options is invoked depends on the number of numeric values provided. To enter the coefficient of a single pipe the format is

	Link #	Coefficient
COEFFICIENT	11	95

This will override the coefficient previously entered for the indicated pipe link, either under the keyword PIPE or COEF. To enter the coefficient of a group of pipes, the format is

	Link #	Link #	Coefficient
COEFFICIENT	11	37	95

In this case the Hazen-Williams coefficient of all the existing pipes with numbers in the range 11 through 37 (inclusive) will be changed to 95. Links other than pipes in the indicated range (pumps, PRVs) are not affected. To change the default value, the format is

	Coefficient
COEFFICIENT	120

In this case the C-factor for all pipes that were assigned the default value is changed to the new default value. Note that in all three cases the last value is the new coefficient.

k. ACCURACY. This keyword is used to specify the accuracy to which computations should be carried and (as an option) the maximum number of iterations to be performed. The user specifies a pressure accuracy in pounds per square inch and a flow accuracy in gallons per minute. The largest error in the system will be less than the value entered under this keyword. For an exact definition of the term "accuracy," see Part 2 of this manual, Documentation. If the ACCURACY keyword is not used, the program uses the following default values: pressure accuracy, 2 pounds per square inch; flow accuracy, 10 gallons per minute; number of iterations, 25. The format for this keyword is given below.

	Pressure accuracy (psi)	Flow accuracy (gpm)	Number of iterations (optional)
ACCURACY	4	20	10

The number of iterations is optional. The program uses a numeric technique in which the head loss equations of all pipes (or characteristic curve of the pumps) are linearized and solved simultaneously with the continuity equation

of all nodes. Such a technique shows excellent convergence. The number of iterations required is independent of the number of nodes and pipes in the system. A system without PRVs and without check valves typically converges within five to seven iterations for a flow accuracy of 1 gallon per minute and pressure accuracy of 1 pound per square inch. (Typically, the flow accuracy is the controlling factor.) Systems with PRVs and/or check valves require roughly twice as many iterations. After the use of the keyword ACCU, the keyword will be changed back to PIPE.

1. PUMP. This keyword is used to enter data for a pump. First, the link number and its end nodes are entered. Note that pumps are numbered in the same manner as pipe and PRV numbers. Do not use the same link number for a pipe and a pump or PRV.

	Link #	Node #	Node
PUMP	78	81	82

While the order of the node numbers does not matter when entering data under the keyword PIPE, the order here is important. The pump is assumed to pump from the first node number listed to the second one. If the extended period portion of the program is to be used to model parallel pumps, insert short (e.g., 1-foot) links on either side of the pumps connecting to a common node so that if one pump turns off, it will not affect the other. The illustration below shows the correct and incorrect way to enter parallel pumps for the extended period simulation. For steady-state simulation, either method is acceptable.

```
  /0--pump 1--0\              ----pump 1----
 O              O           O                O
  \0--pump 2--0/              ----pump 2----

    CORRECT                     INCORRECT

               0 = node
```

The pump entry is followed by the prompt:

POINT xx ON CHARACTERISTIC CURVE: ENTER DISCHARGE, HEAD

This prompt appears three times. At xx the numbers 1, 2, and 3 will appear, respectively. The discharge is to be entered in gallons per minute, and the head is entered in feet. If the quadratic equation fitted through the three points does not meet the requirements listed in paragraph 28-12e, the program will print an error message and reject the data. The user may enter only the first point and respond to the second request with the letter E (for EXIT). The program will then default to a characteristic curve that has a head of 133.3 percent of the head entered for point 1 at flow zero and a head of zero at a discharge twice the discharge entered for point 1 (see Figure 28-4). After the three points are entered, the program will print the coefficients and return to the standard input prompt under the keyword PUMP. The units of

the coefficients are such that flow is in cubic feet per second and head is in feet. Up to 20 pumps can be used in a system.

m. PRV. Note that this keyword has only three characters. It is used to enter data for PRVs. First the link number and its end nodes are entered in the same manner as a pump. The format for this keyword is given below.

	Link #	Node #	Node
PRV	278	113	101

The PRV is assumed to allow flow only from the first node number listed to the second one since PRVs also act as check valves. The constant pressure, if possible, will be maintained at the second node listed. This entry is followed by the prompt:

ENTER PRESSURE SETTING

The pressure setting is given in pounds per square inch. After the pressure setting is entered, the program will return to the input prompt under the keyword PRV.

n. CHECK. This keyword is used to insert a check valve into a previously entered pipe. The format for this keyword is given below.

	Link #	Node #	Node
CHECK	27	97	84

The program will assume that the check valve will allow flow only from the first to the second node. If the indicated pipe number was not previously entered or the node numbers do not match those previously entered for this pipe, the program will print an error message and reject the data.

o. NODE. This keyword offers an alternative to the use of the keywords ELEVATION and OUTPUT for entering data pertaining to a node. It is most conveniently used if the user first enters all the pipe, pump, and PRV data. He can then enter the keyword NODE without any numeric values:

NODE

The program will now respond with the following prompt:

FOR NODE xx ENTER ELEVATION OUTPUT

At xx the node number for which data are requested will appear, starting with the lowest node number used for a beginning or ending node of a link. The numeric value for OUTPUT is optional. For instance, nodes with constant head will require only the elevation on this line of data. If the keyword NODE is used after some node elevations were already entered under the keyword ELEVATION, these nodes will be skipped. The keyword NODE can also be used if at a later time the system is expanded. The program will then prompt only for those nodes just added. For example, if a user entered a pipe from node 7 to

node 10, and the elevation for node 10 had not been specified, the user could enter NODE, to which the program would respond FOR NODE 10 ENTER ELEVATION OUTPUT and the user would respond "150   25" to indicate that the elevation of the node is 150 feet and the water use is 25 gallons per minute. After the data for all nodes have been entered, the program returns to the standard prompt with the keyword TANK.

p. RATIO. This keyword is used to multiply the present output (entered under the keyword OUTPUT or NODE) at a sequence of nodes or all nodes by the indicated factor. For example, this keyword is used to simulate peak day flows if the output data entered under the keyword OUTPUT correspond to average day flow. Note that there are two formats for this keyword. The format for changing the output at a sequence of nodes is

	Node #	Node #	Ratio
RATIO	10	47	1.8

The present output at all nodes with numbers between 10 and 47 (inclusive) will be multiplied by the indicated ratio. The format to change the output at all nodes is

	Ratio
RATIO	1.8

In both cases, nodes that were designated as constant head nodes (reservoirs, tanks) and nodes that were assigned an input are not affected. Note that in both formats the last value is the ratio.

q. CREA. This keyword is used to store a system that has only partially been entered. It should be used when all of a system cannot be entered during one session. The format for the keyword is given below:

CREA   DATFIL

where DATFIL is the name of the file on which the partial system data will be stored. This name is optional; if not entered, data will be stored on file SYSDA.

r. GET. This keyword is used to retrieve system data from a system that was only partially entered. The format for the keyword is given below.

GET   DATFIL

where DATFIL is name of the file on which the partial system data were stored. If no name is given, file SYSDA will be read from. Only partial data files (interim data files) should be retrieved using keyword GET. Complete data files should be retrieved by selecting the RETRIEVE DATA option from the option menu. For additional information on storing and retrieving data, see Appendix B (Cybernet) and Appendix C (IPM PC).

s. Deleting Elements. The user can delete links. If the deletion of a link results in a completely disconnected node, the program will automatically delete this node and all data associated with it. The link is deleted using any one of the regular link keywords (PIPE, LINE, PUMP, or PRV) followed by the link number and a 0 (zero). For instance, "PUMP 117 0" would delete the pump with number 117. Since the program does not check on the type of element being deleted, in the above example, PIPE 117 0 would accomplish the same thing, as would PRV 117 0. Check valves are removed from a pipe by reentering the complete pipe.

t. END. This keyword will terminate the data entry routine. The program will return to the main simulation option menu.

u. Printing the Input Data. Upon entering the keyword END, program control returns to the main option menu. The user can select option 2 or 2C to review the input data. The program will print two tables.

(1) The first table is a node table that gives node number; elevation, feet; output, gallons per minute; and comment. The comment column is used to flag the constant head points with either the word RESERVOIR or TANK. A negative value in the output column indicates a flow input.

(2) The second table is a link table (including pipes with check valves, pumps, and PRVs) that gives link number; beginning node; ending node; diameter, inches; length, feet; Hazen-Williams coefficient (* indicates default value); and comment. For pipes with a check valve, the words CHECK VALVE appear in the comment column. In the case of pumps, the word PUMP is printed in this column. In the case of PRVs, "PRV AT xx PSI" is printed in the comment column. At xx the pressure setting of the PRV is printed.

(3) An example of the printed input is shown in Table 28-3. After printing the input data, program control returns to the main option menu (see paragraph 28-9).

28-14. Balancing of System. To balance the system (compute pressure and flow distribution), the user takes option 0 or 0C in the main option menu. The program first lists the pressure and flow accuracy limits. It then prints the estimated maximum error at the end of every iteration. For example:

```
ACCURACY LIMITS:   2.0 PSI;    10.0 GPM
ESTIMATED MAXIMUM ERRORS:
ITERATION #  1:  61.7 PSI AT NODE 14;     3312. GPM AT NODE 5
   etc.
SYSTEM IS BALANCED
```

The program proceeds with printing the output. If the system is not properly balanced after the specified maximum number of iterations, the program prints a warning message.

Table 28-3. Input Data for Example 1

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXAMPLE 1

NODE NO	ELEV. FT.	OUTPUT GPM	
2	950.0		WATER LEVEL: 100.0
3	910.0	0.	
6	905.0	50.	
11	950.0		RESERVOIR
12	970.0	0.	
13	920.0	0.	
15	890.0	80.	
16	890.0	75.	
25	890.0	0.	
26	890.0	0.	
33	870.0	50.	
34	870.0	0.	
35	870.0	75.	
36	850.0	1500.	

PIPE CONNECTIONS

PIPE NO.	B NODE	E NODE	DIAM. IN.	LENGTH FT.	H-W-C	
11	3	13	8.0	1800.0	100.*	
13	6	16	10.0	1000.0	100.*	
22	15	25				PRV AT 60.0 PSI
23	16	26				PRV AT 60.0 PSI
31	13	33	8.0	1000.0	100.*	
32	25	35	8.0	1000.0	100.*	
33	26	36	8.0	1000.0	100.*	
101	2	3	12.0	2000.0	100.*	
102	3	6	10.0	1500.0	100.*	
110	11	12				PUMP
111	12	13	12.0	5000.0	100.*	
112	13	15	8.0	1500.0	100.*	
114	15	16	8.0	1500.0	100.*	
122	33	34				PRV AT 60.0 PSI
123	34	35	8.0	1500.0	100.*	
124	35	36	8.0	1500.0	100.*	

PUMP COEFFICIENTS FOR PUMP 110

Q*Q	Q	CONSTANT
-3.7772	-1.1221	151.3

28-15. Output. Output is provided automatically after balancing (option 0 or 0C). Also, if a system is balanced when the main option menu is displayed, option 6 or 6C is available and will access the output routine.

a. Node Table. The first table that is printed lists all nodes. Data given include:

(1) Node number.
(2) Elevation of node, feet.
(3) Output, gallons per minute.
(4) Elevation of hydraulic grade line (E.G.L.), feet.
(5) Head, feet.
(6) Pressure, pounds per square inch.
(7) Comment.

The output column shows the output (positive value) or input (negative value) as specified under the keywords OUTPUT and INPUT, respectively. At constant head nodes (tanks or reservoirs), a negative value indicates the net inflow from the tank or reservoir into the system; a positive value indicates the net outflow from the system into the tank or reservoir. The comment column flags the constant head nodes with either the word RESERVOIR or TANK.

b. Link Table. The second table printed lists all pipes (including those with check valves), pumps, and PRVs. The table gives:

(1) Link number.
(2) Node number from which the flow comes.
(3) Node number toward which the flow goes.
(4) Diameter, inches (PRV or check valve status).
(5) Length, feet.
(6) Hazen-Williams coefficient (* indicates default value).
(7) Flow, gallons per minute.
(8) Velocity, feet per second.
(9) Head loss, feet (pump horsepower).

Note that the flow direction is indicated by the order in which the node numbers are listed. In the case of pumps, the word PUMP appears in column 4 followed by the pump head, and the discharge of the pump in column 7 again followed by the (hydraulic) power produced by the pump in horsepower. In the case of PRVs, the word PRV appears in column 4, followed by the pressure setting and one of the words ACTIVE, CLOSED, or OPEN, depending on the mode in which the PRV operates (see 28-12f). For pipes with check valves, the information is the same as for a regular pipe if the check valve is open, with the letters CV printed in the right margin of the table. If the check valve is closed, "CHECK VALVE CLOSED" is printed, starting in column 4. An example of the printed output is shown in Table 28-4.

28-16. Consecutive Runs. After a system is balanced and output is printed, control returns to the main option menu. If at this point option 0 or 0C is selected, the program will continue balancing the system to a higher degree of accuracy even if the accuracy requested is not changed. This is because the

Table 28-4. First Output for Example 1

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXAMPLE 1

NODE DATA   Page 1

NODE NO.	ELEV. FT.	OUTPUT GPM	E.G.L. FT.	PR.HEAD FT.	PRESSURE PSI	
2	950.0	-720.	1050.0	100.0	43.3	SUPPLY
3	910.0		1045.5	135.5	58.7	
6	905.0	50.	1030.6	125.6	54.4	
11	950.0	-1109.	950.0			RESERVOIR
12	970.0		1075.4	105.4	45.7	
13	920.0		1050.3	130.3	56.5	
15	890.0	80.	1022.0	132.0	57.2	
16	890.0	75.	1021.6	131.6	57.0	
25	890.0		1022.0	132.0	57.2	
26	890.0		1021.6	131.6	57.0	
33	870.0	50.	1050.2	180.2	78.1	
34	870.0		1009.4	139.4	60.4	
35	870.0	75.	1009.4	139.4	60.4	
36	850.0	1500.	994.5	144.5	62.6	

PIPE DATA

PIPE NO.	NODES FROM	NODES TO	DIAM. IN.	LENGTH FT.	COEF	FLOW GPM	VEL. FT/SEC	HEAD LOSS
11	13	3	8.0	1800.0	100.*	273.	1.7	4.9
13	6	16	10.0	1000.0	100.*	941.	3.8	9.0
22	15	25	PRV AT	60.0 PSI	OPEN			
23	16	26	PRV AT	60.0 PSI	OPEN			
31	13	33	8.0	1000.0	100.*	51.	.3	.1
32	25	35	8.0	1000.0	100.*	627.	4.0	12.6
33	26	36	8.0	1000.0	100.*	947.	6.0	27.1
101	2	3	12.0	2000.0	100.*	720.	2.0	4.5
102	3	6	10.0	1500.0	100.*	991.	4.0	14.9
110	11	12	PUMP HEAD	125.4	FT	1109.	POWER	35. HP
111	12	13	12.0	5000.0	100.*	1107.	3.1	25.1
112	13	15	8.0	1500.0	100.*	780.	5.0	28.4
114	15	16	8.0	1500.0	100.*	79.	.5	.4
122	33	34	PRV AT	60.0 PSI	CLOSED			
123	35	34	8.0	1500.0	100.*	0.	.0	.0
124	35	36	8.0	1500.0	100.*	551.	3.5	14.9

program will always go through at least three iterations. The user can also select option 1, which returns control to the input routine as described in paragraph 28-13. At this point the user can change any parameter in the system, expand the system, or delete part of the system. The keywords used are the same as described in paragraph 28-13. Upon entering the keyword END, control returns to the main option menu, and the user can balance the system again or select any other option available.

28-17. Storing Data. In the main option menu the user can select option 3 to store the input data before balancing or both the input and output data after balancing. The program will respond with the prompt ENTER FILE NAME. The user enters any file name that conforms with the file name requirements of the computer system. If a balanced system is stored, the output is stored with all the system parameters. The only exception is the net outflow at constant head tanks, which is not stored. For additional information on storing data files refer to Appendix B (Cybernet) and Appendix C (IBM PC). Data stored that way can be retrieved again through option 2 in the start-up menu (see paragraph 28-8) or option 4 in the main option menu.

28-18. Example 1. The network for this example is shown in Figure 28-5. The purpose of the example is to illustrate first the data input routine. The program will then be rerun a number of times to illustrate some of the options available. Below, a run of the program is shown, from the point when the program has begun. Lines without a question mark are the prompts printed by the program. The user's input appears after the question marks.

```
PROGRAM CONTROL :
     SIMULATION          : ENTER  1  PRESS RETURN
     OPTIMIZATION        :        2
     COST DATA           :        3
     TERMINATE PROGRAM   :        9
? 1
SIMULATION ROUTINE

SELECT PROGRAM OPTION :
     TO ENTER NEW JOB :  ENTER    1  PRESS RETURN
     TO RETRIEVE DATA :           2

? 1
S. KEYWORD IS JOB ENTER (KEYWORD) DATA LIST
? EXAMPLE 1
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST      ---
? 101 2 3 12 2000                                    )
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST         )
? 102 3 6 10 1500                                    )
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST         )
? 111 12 13 12 5000                                  )
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST         )
? 112 13 15 8 1500                                   )
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST         )
```

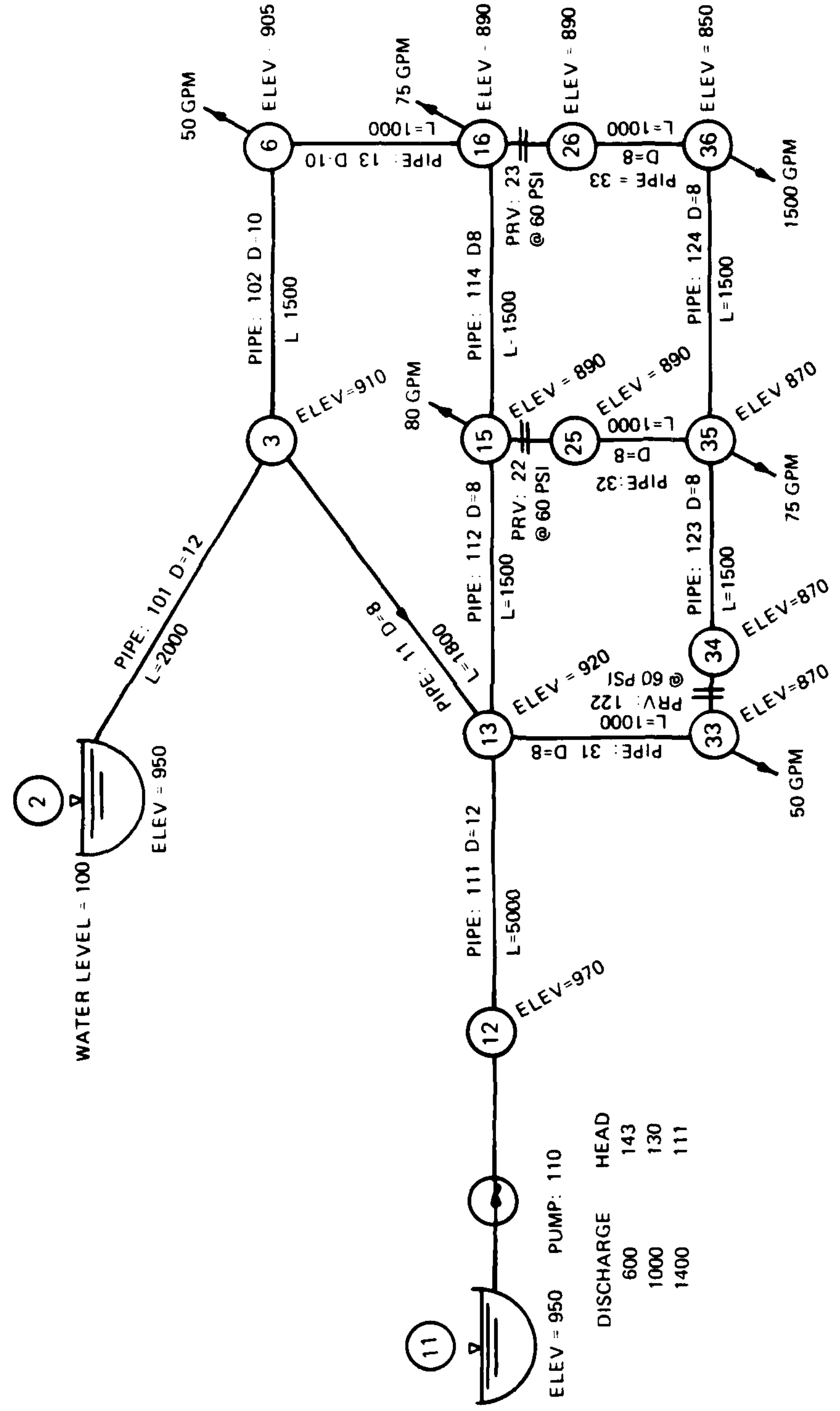

Figure 28-5. System layout example

```
? 114 15 16 8 1500                                            )
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST                  )
? 123 34 35 8 1500                                            )     Pipe Data
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST                  )
? 124 35 36 8 1500                                            )
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST                  )
? 11 3 13 8 1800                                              )
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST                  )
? 13 6 16 10 1000                                             )
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST                  )
? 31 13 33 8 1000                                             )
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST                  )
? 32 25 35 8 1000                                             )
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST                  )
? 33 26 36 8 1000                                             )
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST                ---
? PRV 22 15 25                                                )
ENTER PRESSURE SETTING                                        )
? 60                                                          )
S. KEYWORD IS PRV ENTER (KEYWORD) DATA LIST                   )
? 23 16 26                                                    )     PRV Data
ENTER PRESSURE SETTING                                        )
? 60                                                          )
S. KEYWORD IS PRV ENTER (KEYWORD) DATA LIST                   )
? 122 33 34
ENTER PRESSURE SETTING                                        )
? 60                                                          )
S. KEYWORD IS PRV ENTER (KEYWORD) DATA LIST                   -------
? PUMP 110 11 12                                                   )
POINT 1 ON CHARACTERISTIC CURVE:  ENTER DISCHARGE, HEAD            )
? 600 143                                                          )     Pump
POINT 2 ON CHARACTERISTIC CURVE:  ENTER DISCHARGE, HEAD            )     Data
? 1000 130                                                         )
POINT 3 ON CHARACTERISTIC CURVE:  ENTER DISCHARGE, HEAD            )
? 1400 111
S. KEYWORD IS PUMP ENTER (KEYWORD) DATA LIST                  -------
? NODE                                                        )
FOR NODE  2  ENTER  ELEVATION OUTPUT                          )
? 950                                                         )
FOR NODE  3  ENTER  ELEVATION OUTPUT                          )
? 910                                                         )
FOR NODE  6  ENTER  ELEVATION OUTPUT                          )
? 905 50                                                      )     Node Data
FOR NODE 11  ENTER  ELEVATION OUTPUT                          )
? 950                                                         )
FOR NODE 12  ENTER  ELEVATION OUTPUT                          )
? 970                                                         )
FOR NODE 13  ENTER  ELEVATION OUTPUT                          )
? 920                                                         )
FOR NODE 15  ENTER  ELEVATION OUTPUT                          )
? 890 80                                                      )
```

```
FOR NODE 16  ENTER  ELEVATION OUTPUT              )
? 890 75                                          )
FOR NODE 25  ENTER  ELEVATION OUTPUT              )     Node Data
? 890                                             )
FOR NODE 26  ENTER  ELEVATION OUTPUT              )
? 890                                             )
FOR NODE 33  ENTER  ELEVATION OUTPUT              )
? 870 50                                          )
FOR NODE 34  ENTER  ELEVATION OUTPUT              )
? 870                                             )
FOR NODE 35  ENTER  ELEVATION OUTPUT              )
? 870 75                                          )
FOR NODE 36  ENTER  ELEVATION OUTPUT              )
? 850 1500                                        )
S. KEYWORD IS TANK ENTER (KEYWORD) DATA LIST    ---
? 11 0                                            )
S. KEYWORD IS TANK ENTER (KEYWORD) DATA LIST      )    Tank Data
? 2 100                                           )
S. KEYWORD IS TANK ENTER (KEYWORD) DATA LIST      )
? END                                            ---
```

After the menu appears, select option 2, PRINT INPUT. The node and link table for the input data is shown in Table 28-3. In the menu, select option 0, BALANCE. The program will respond with printing the accuracies, iteration by iteration, as shown below.

```
ACCURACY LIMITS:     2.0 PSI;     10.0 GPM
ESTIMATED MAXIMUM ERRORS:

ITERATION #  1 :    61.7 PSI AT NODE 14:     3312. GPM AT NODE  5
ITERATION #  2 :    31.0 PSI AT NODE  5:      625. GPM AT NODE  6
ITERATION #  3 :     9.1 PSI AT NODE 12:      663. GPM AT NODE 11
ITERATION #  4 :     3.4 PSI AT NODE 12:      228. GPM AT NODE  7
ITERATION #  5 :     1.4 PSI AT NODE  7:      126. GPM AT NODE  7
ITERATION #  6 :     1.9 PSI AT NODE  9:       58. GPM AT NODE  7
ITERATION #  7 :      .6 PSI AT NODE 14:       27. GPM AT NODE  7
ITERATION #  8 :      .3 PSI AT NODE 14:       12. GPM AT NODE  7
ITERATION #  9 :      .1 PSI AT NODE 14:        6. GPM AT NODE  7

SYSTEM IS BALANCED
```

The output is shown in Table 28-4. Note that PRVs 22 and 23 are OPEN because the upstream pressure is below the pressure setting. PRV 122 is CLOSED because the downstream pressure is larger than the pressure setting. Consequently, pipe 123 has exactly zero flow. If the network could be perfectly balanced, pump 110 and pipe 111 would show the same flow. However, the accuracy for flow rates defaulted to 10 gallons per minute. In the last iteration the model had actually reached a flow accuracy of 6 gallons per minute. To show how the accuracy can be further improved, once more enter option 0 in the main option menu. With the accuracy limits unchanged, the program will execute three iterations.

```
ACCURACY LIMITS:     2.0 PSI;     10.0 GPM
ESTIMATED MAXIMUM ERRORS:

ITERATION #  1 :      .1 PSI AT NODE 14;        3. GPM AT NODE  7
ITERATION #  2 :      .0 PSI AT NODE 14;        1. GPM AT NODE  7
ITERATION #  3 :      .0 PSI AT NODE 14;        1. GPM AT NODE  7

SYSTEM IS BALANCED
```

The output is shown in Table 28-5. After the system was balanced the first time, the largest change in any flow rate was 4 gallons per minute and the largest change in pressure was 0.1 pound per square inch, both consistent with the estimated accuracies. Assume now that a check valve is inserted into pipe 11 limiting the flow from 3 to 13. This change should result in a considerable change in the system since, at present, 247 gallons per minute are flowing through this pipe toward the tank. Also, the Hazen-Williams coefficient is to be changed to 120 for all pipes. From the option menu, take option 1. The prompts and responses are reproduced below.

```
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? CHECK 11 3 13
S. KEYWORD IS CHEC ENTER (KEYWORD) DATA LIST
? COEF 120
S. KEYWORD IS COEF ENTER (KEYWORD) DATA LIST
? END
```

In Table 28-6 the output for this run is reproduced. The accuracies after the last iteration are estimated to be 0.2 pound per square inch and 9 gallons per minute. Note that PRVs 22 and 23 have switched to active mode. The check valve in pipe 11 is closed. In the last change the output is reduced by 10 percent (multiplication factor 0.9) and an output of 1,800 gallons per minute is assigned to node 36. Also, output at node 35 is to be eliminated. From the main option menu, select option 1.

```
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? RATIO .9
S. KEYWORD IS RATI ENTER (KEYWORD) DATA LIST
? OUTPUT 36 1800
S. KEYWORD IS OUTP ENTER (KEYWORD) DATA LIST
? 35 0
S. KEYWORD IS OUTP ENTER (KEYWORD) DATA LIST
? END
```

The output for the balanced system is shown in Table 28-7. The accuracies are estimated at 0.3 pound per square inch and 7 gallons per minute. This concludes Example 1.

Section 4. Program Control for Optimization Routine

28-19. Introduction. The optimization routine is accessed from the program control menu (see paragraph 28-8) by selecting option 2. This routine is then

Table 28-5. Output for Example 1 After Second Balancing

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXAMPLE 1

NODE DATA Page 1

NODE NO.	ELEV. FT.	OUTPUT GPM	E.G.L. FT.	PR.HEAD FT.	PRESSURE PSI	
2	950.0	-722.	1050.0	100.0	43.3	SUPPLY
3	910.0		1045.5	135.5	58.7	
6	905.0	50.	1030.5	125.5	54.4	
11	950.0	-1108.	950.0			RESERVOIR
12	970.0		1075.5	105.5	45.7	
13	920.0		1050.3	130.3	56.5	
15	890.0	80.	1021.8	131.8	57.1	
16	890.0	75.	1021.4	131.4	56.9	
25	890.0		1021.8	131.8	57.1	
26	890.0		1021.4	131.4	56.9	
33	870.0	50.	1050.2	180.2	78.1	
34	870.0		1009.2	139.2	60.3	
35	870.0	75.	1009.2	139.2	60.3	
36	850.0	1500.	994.3	144.3	62.5	

PIPE DATA

PIPE NO.	NODES FROM	TO	DIAM. IN.	LENGTH FT.	COEF	FLOW GPM	VEL. FT/SEC	HEAD LOSS
11	13	3	8.0	1800.0	100.*	274.	1.7	4.9
13	6	16	10.0	1000.0	100.*	945.	3.9	9.1
22	15	25	PRV AT	60.0 PSI	OPEN			
23	16	26	PRV AT	60.0 PSI	OPEN			
31	13	33	8.0	1000.0	100.*	50.	.3	.1
32	25	35	8.0	1000.0	100.*	627.	4.0	12.6
33	26	36	8.0	1000.0	100.*	948.	6.1	27.1
101	2	3	12.0	2000.0	100.*	722.	2.0	4.5
102	3	6	10.0	1500.0	100.*	995.	4.1	15.0
110	11	12	PUMP HEAD	125.5 FT		1108.	POWER	35. HP
111	12	13	12.0	5000.0	100.*	1108.	3.1	25.1
112	13	15	8.0	1500.0	100.*	784.	5.0	28.6
114	15	16	8.0	1500.0	100.*	78.	.5	.4
122	33	34	PRV AT	60.0 PSI	CLOSED			
123	35	34	8.0	1500.0	100.*	0.	.0	.0
124	35	36	8.0	1500.0	100.*	552.	3.5	14.9

Table 28-6. Output for Example 1 After Adding Check Valve and Changing Pipe Coefficients

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXAMPLE 1

NODE DATA Page 1

NODE NO.	ELEV. FT.	OUTPUT GPM	E.G.L. FT.	PR.HEAD FT.	PRESSURE PSI	
2	950.0	-816.	1050.0	100.0	43.3	SUPPLY
3	910.0		1045.9	135.9	58.9	
6	905.0	50.	1038.5	133.5	57.8	
11	950.0	-998.	950.0			RESERVOIR
12	970.0		1080.1	110.1	46.7	
13	920.0		1065.4	145.4	63.0	
15	890.0	80.	1036.5	146.5	63.5	
16	890.0	75.	1034.1	144.1	62.4	
25	890.0		1028.5	138.5	60.0	
26	890.0		1028.5	138.5	60.0	
33	870.0	50.	1065.3	195.3	84.6	
34	870.0		1019.6	149.6	64.8	
35	870.0	75.	1019.6	149.6	64.8	
36	850.0	1500.	1009.1	159.1	68.9	

PIPE DATA

PIPE NO.	NODES FROM	TO	DIAM. IN.	LENGTH FT.	COEF	FLOW GPM	VEL. FT/SEC	HEAD LOSS
11	3	13	CHECK VALVE			CLOSED		
13	6	16	10.0	1000.0	120.*	767.	3.1	4.4
22	15	25	PRV AT	60.0 PSI		ACTIVE		
23	16	26	PRV AT	60.0 PSI		ACTIVE		
31	13	33	8.0	1000.0	120.*	50.	.3	.1
32	25	35	8.0	1000.0	120.*	623.	4.0	8.9
33	26	36	8.0	1000.0	120.*	950.	6.1	19.4
101	2	3	12.0	2000.0	120.*	816.	2.3	4.1
102	3	6	10.0	1500.0	120.*	817.	3.3	7.4
110	11	12	PUMP HEAD	130.1 FT		998.	POWER	33. HP
111	12	13	12.0	5000.0	120.*	996.	2.8	14.7
112	13	15	8.0	1500.0	120.*	945.	6.0	28.8
114	15	16	8.0	1500.0	120.*	249.	1.6	2.4
122	33	34	PRV AT	60.0 PSI		CLOSED		
123	35	34	8.0	1500.0	120.*	0.	0.0	0.0
124	35	36	8.0	1500.0	120.*	548.	3.5	10.5

Table 28-7. Output for Example 1 After Changing the Outputs

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXAMPLE 1

NODE DATA Page 1

NODE NO.	ELEV. FT.	OUTPUT GPM	E.G.L. FT.	PR.HEAD FT.	PRESSURE PSI	
2	950.0	-972.	1050.0	100.0	43.3	SUPPLY
3	910.0		1044.4	134.4	58.2	
6	905.0	45.	1034.1	129.1	55.9	
11	950.0	-1043.	950.0			RESERVOIR
12	970.0		1078.2	108.2	46.9	
13	920.0		1062.2	142.2	61.6	
15	890.0	72.	1030.3	140.3	60.8	
16	890.0	68.	1027.9	137.9	59.7	
25	890.0		1028.5	138.5	60.0	
26	890.0		1027.9	137.9	59.7	
33	870.0	45.	1062.1	192.1	83.2	
34	870.0		1017.8	147.8	64.1	
35	870.0		1017.8	147.8	64.1	
36	850.0	1800.	1001.9	151.9	65.8	

PIPE DATA

PIPE NO.	NODES FROM	TO	DIAM. IN.	LENGTH FT.	COEF	FLOW GPM	VEL. FT/SEC	HEAD LOSS
11	3	13	CHECK VALVE			CLOSED		
13	6	16	10.0	1000.0	120.*	927.	3.8	6.3
22	15	25	PRV AT	60.0 PSI		ACTIVE		
23	16	26	PRV AT	60.0 PSI		OPEN		
31	13	33	8.0	1000.0	120.*	45.	.3	.1
32	25	35	8.0	1000.0	120.*	687.	4.4	10.6
33	26	36	8.0	1000.0	120.*	1112.	7.1	26.0
101	2	3	12.0	2000.0	120.*	972.	2.8	5.6
102	3	6	10.0	1500.0	120.*	972.	4.0	10.2
110	11	12	PUMP HEAD	128.2 FT		1043.	POWER	34. HP
111	12	13	12.0	5000.0	120.*	1043.	3.0	16.0
112	13	15	8.0	1500.0	120.*	998.	6.4	31.9
114	15	16	8.0	1500.0	120.*	247.	1.6	2.4
122	33	34	PRV AT	60.0 PSI		CLOSED		
123	35	34	8.0	1500.0	120.*	0.	0.0	0.0
124	35	36	8.0	1500.0	120.*	686.	4.4	16.0

controlled from three menus. One menu provides for the main options of the routine. Two more menus are used when accessing the cost data option. Note that the cost data option can be accessed directly from the program control menu.

28-20. Option Menu. The option menu of the optimization routine is accessed either from the program control menu or after an option previously selected in this menu is completed. The menu allows the user to select from optimizing the network, entering and/or modifying the optimization parameters, printing the optimization data, storing the data under a user-selected file name, retrieving the optimization data from a file in which the data were previously stored with the preceding option, returning to the program control menu, and terminating the program. The option menu as displayed at the terminal is shown below.

```
SELECT PROGRAM OPTION:

OPTIMIZE                  : ENTER  0  OR OE PRESS RETURN
ENTER/MODIFY OPT. DATA :         1
PRINT OPT. DATA           :         2
STORE OPT. DATA           :         3
RETRIEVE OPT. DATA        :         4
ENTER/MODIFY COST DATA :         5
PROGRAM CONTROL           :         8
TERMINATE PROGRAM         :         9
```

After the completion of options 0 through 5, control returns to this option menu.

a. OPTIMIZE. This option starts the optimization procedure. For more details, see paragraph 28-29.

b. ENTER/MODIFY OPT. DATA. This option allows the user to enter the data input routine as described in paragraph 28-26. There, any of the optimization parameters can be changed.

c. PRINT OPT. DATA. This option prints a list of all optimization data. (See paragraph 28-27.)

d. STORE OPT. DATA. To store the optimization data in an internal data file, the user must access the store routine using this option. The program does not store the data automatically. (See paragraph 28-28.)

e. RETRIEVE OPT. DATA. This option allows the user to retrieve data that were stored under d. above.

f. ENTER/MODIFY COST DATA. This option allows the user to enter a new cost data file or to update a previously entered cost data file.

g. PROGRAM CONTROL. This option will transfer program control back to the program control menu.

h. TERMINATE PROGRAM. This option will terminate the computer run.

Section 5. Optimization of Distribution System

28-21. Introduction. Optimization consists of selection of the least-cost combination of pipes subject to a set of constraints (e.g., minimum pressures, ranges of pipe sizes) provided by the user. The intent of the optimization routine is to use these constraints to size specific pipes in the system. The program will enumerate all possible size combinations and select the solution with the lowest total cost within the constraints specified (including energy cost for pumping if desired). The procedure guarantees the global minimum within the specified constraints. The optimization routine also allows the user to consider the cleaning and relining of existing pipes. The optimization can be carried out for more than one output/input pattern of flows. The optimization routine will also determine Pareto Optimal solutions that are close to the original solution in terms of cost and minimum pressure. A combination of pipe sizes is said to be a Pareto Optimal (noninferior) solution if there is no other solution that has better pressure at a lower cost. The program will relax the minimum pressure constraint to allow other solutions that result in costs within a certain percentage of the original cost. Pressure is judged at the node with the lowest pressure compared with the required pressure. The degree to which the pressure constraint is relaxed and the allowable percentage variation in cost are values that can be specified, or the user can rely on default values. An overview of the steps required to optimize a network is given below.

a. Enter or retrieve network simulation data.

b. Run simulation to set up internal tables.

c. Enter or retrieve cost data.

d. Enter or retrieve optimization data.

(1) Identify pipes to be optimized by assigning them to groups.

(2) Identify a price function for each pipe to be sized.

(3) Identify allowable sizes for new pipes.

(4) Identify loadings to be analyzed.

(5) Identify pressure constraints.

e. Run optimization.

28-22. Definition of Terms. The following terms will be used in connection with the optimization routine:

a. Group. A group consists of one or several pipes with the same diameter, to be sized in the optimization routine. The user indicates which pipes

are to be optimized by assigning the pipes to a group. Pipes not assigned to a group have a fixed diameter corresponding to the diameter specified during the simulation.

b. Price Functions. In the cost data file the user can enter different price functions for a discrete set of pipe sizes. A price function represents a list of pipe sizes and, for each size, an installation cost (dollars per foot). Different price functions can be specified, so that, for example, a 12-inch pipe to be installed under a city street will cost more than a 12-inch pipe installed in a new subdivision. This relationship can hold (if so designated) even if both 12-inch pipes are in the same group. Other examples: one price function may refer to the cost for "average conditions," a second function for shallow pipes, a third one for deep pipes, a fourth one for typical city conditions, etc. Each pipe to be sized is assigned to a price function. Pipes in the same group may be assigned to different price functions.

c. Sizes. In the context of the optimization routine, sizes (in inches) refer to a list of discrete pipe sizes from which the program selects the optimum size for a particular group. Each group can have a different set of sizes. Only those pipe sizes identified for a group will be considered.

d. Minimum Pressure. Pipe sizes will be selected such that at all nodes (excluding reservoirs and the nodes at the foot of tanks), the pressure is equal to or larger than the minimum pressure (in pounds per square inch) specified for the particular node.

e. Loading (or Loading Pattern). A set of flow outputs or inputs to be applied simultaneously is defined as a loading. One loading may be the peak flow expected during a normal day, while another may represent the flows necessary to fight a fire at a specific node. The program will consider all loading patterns (up to five) that the user specifies and will determine the network that is capable of handling flows for all patterns. In addition to flow outputs, different minimum pressure patterns can be specified for different loading patterns.

f. Redundancy. Redundancy in a system refers to the fact that there is more than one path for water to take to a particular node.

28-23. Optimization Data. The optimization routine requires the designation of five types of optimization data.

a. Pipe Grouping. Each pipe to be sized is assigned to one and only one group. All pipes in the same group will be assigned the same diameter during the optimization routine. This constraint is very important in three ways. First, for reasons of constructing a distribution system, it is not desirable to have potentially different sizes for each leg of pipe. Such solutions are the result of a particular loading pattern. Slight changes in the pattern could result in different sizes. Grouping allows the user to control where pipe size changes may occur. Second, grouping of pipes provides the user with a powerful tool to control to some degree the optimization, that is the direction in which to look for an answer. On the other hand, careless usage of the

tool may result in poor solutions. Third, because of the two reasons listed above which make grouping desirable, the methodology employed by the optimization routine takes advantage of the grouping in order to keep computer time within reason. A large number of groups may result in excessive computer time.

b. Cost Information. The user may enter cost data in the cost data input portion of the program or use default cost data stored in the program. The data include costs for each size for one or several price functions (see paragraph 28-22b). The user also indicates which pipe link belongs to which price function. Costs are represented by a discrete function. The program does not need to interpolate points between sizes. Therefore, no continuous price function needs to be fitted through the points. The price function does not need to meet any particular mathematical requirements (e.g., concave, linear, etc.). The user can build up to 12 price functions. The default data for pipe cost are stored as price function 1, while default data for cleaning and lining are stored as price function 2. These default prices can be overwritten by the user.

c. Size List. The user specifies the pipe sizes to be considered for each group. For example, pipe selection for a group may be limited to 6, 8, 10, and 12 inches. One can specify only the sizes that are included in the discrete price function. Each group can have different sets of sizes. In addition to specifying possible pipe sizes to be considered, the user can specify that the program can consider eliminating all pipes in a group or cleaning and lining the existing pipe(s), if there exists a parallel pipe (not to be sized) to each pipe in the group.

d. Loading Pattern. The user specifies up to five loading patterns to be used in the optimization. Different loading patterns can include variations in outputs at one or more nodes; minimum pressure requirements at one or more nodes; and different specifications for pump operation, including efficiency and the percentage of time it may run under certain loading patterns. A solution is required to meet the pressure constraint for all loading patterns.

e. Pressure Constraint. The user specifies minimum pressures to be met or exceeded in the final solution at as many nodes as desired.

28-24. Redundancy. The importance of redundancy in the part of the system to be sized depends on the particular system. Redundancy is important in the sizing of an entire addition to an existing system. It may be less important, or indeed unnecessary, in the case where the reinforcement to an existing system is to be sized, since the existing system may already provide the necessary redundancy. Redundancy can be controlled in this optimization routine in several ways. First, it is possible in the size list to limit the search for alternatives to specific pipe diameters and not to allow the program to consider cleaning or no new pipe (elimination) (i.e., not to specify 0 or C in the size list). The selected size in the group will then be at least the minimum listed. Redundancy is also controlled through the multiple loading constraint, by assigning a fire load to various nodes. Pipes that could be

eliminated under one loading pattern may be essential in another one in order to meet the pressure constraint. Alternately, two pipes serving a node can be placed in the same group, which would force both pipes to be included with positive diameters.

28-25. Cost Data File.

a. General. The cost data file is a local file in which the user stores one or more price functions to be used in the optimization routine. This paragraph describes how to enter data into the file and how to update the file. The routine can be accessed from the option menu of the optimization routine (paragraph 28-20f) or directly from the program control menu (paragraph 28-8). The option menu of the cost data routine is shown below.

MODIFY DATA	:	ENTER 1	PRESS RETURN
PRINT DATA	:	2	
STORE DATA	:	3	
RETRIEVE DATA	:	4	
PROGRAM CONTROL	:	8	
TERMINATE PROGRAM	:	9	

b. Description of Options. The options operate analogously to the ones discussed in the simulation routine. A brief description of each option follows.

(1) ENTER/MODIFY COST DATA. This option is accessed by taking option 1 in either one of the two menus listed above. It allows the user to enter or modify cost data. (See paragraph 28-25c.)

(2) PRINT COST DATA. This option allows the user to view the data that were entered or modified under (1) above. (See paragraph 28-25d.)

(3) STORE COST DATA. This option allows the user to store the cost data under a user-selected file name. (See paragraph 28-25e.)

(4) RETRIEVE COST DATA. This option is accessed by taking either option 2 in the first menu or option 4 in the second menu. It allows retrieval of data previously stored under option 3. (See paragraph 28-25f.)

(5) PROGRAM CONTROL. This option returns program control to the menu from which the cost data routine was accessed, i.e., either the program control menu or the menu of the optimization routine.

(6) TERMINATE PROGRAM. This option will terminate the computer run.

c. Data Input. The keywords used during data entry are summarized in Table 28-8. Data are requested with the following prompt:

C. KEYWORD IS xxxx ENTER (KEYWORD) DATA LIST

Table 28-8. Keywords for Cost Data File
(C. prompt)

```
END
-------------------------------------------------------
ENERGY     x.xxx
      Energy Cost $/kWh
-------------------------------------------------------
INTEREST      x.x
           Interest in %
-------------------------------------------------------
PRICE     xx
      Price Fct. #
      followed by prompt: FOR SIZE xx.x
      response:          xx.x    (or END)
                       Price $/ft
or
PRICE    xx            xx.x        xx.x
      Price Fct. #    Size in.    Price $/ft
or
PRICE    xx    DELETE
      Price Fct. #
-------------------------------------------------------
SIZE    xx.x    xx.x    xx.x    ...
      List of Sizes in.
or
SIZE    xx.x    DELETE
      Size in.
-------------------------------------------------------
YEAR    xx
      Number of Years
```

The C. indicates that the user is in the cost data routine. At xxxx appears the current keyword. Below, the keywords are listed with the corresponding format for the data list. The first keyword displayed is SIZE.

(1) SIZE. This keyword is used to indicate the pipe sizes for which cost data are to be entered (i.e., the domain of the price function). The format is shown below. Up to 25 different sizes can be specified for a given function.

```
   List of diameters
   (in.)
SIZE 2 4 6 8
```

This entry would enter sizes 2, 4, 6, and 8 inches into the data file. If one of the sizes specified already exists in the data file, this size is not repeated. If the keyword displayed in the prompt is SIZE, the keyword is optional. In order to delete a size from the data file, the format is "SIZE 6 DELETE." If the keyword displayed in the prompt is SIZE, the keyword is optional. DELETE can be abbreviated to DELE. Do not specify a size of 0 (zero).

(2) PRICE. This keyword is used to enter the cost data per linear foot of pipe for sizes specified earlier under the keyword SIZE. There are two formats. In the first format the user enters only the price function number after the keyword.

```
          Function #
     PRICE    4
```

This will cause the program to prompt the user for entry of price data for all sizes from 2 inches to 120 inches. The program will print

```
     FOR PRICE FUNCTION 4 ENTER COST/FT FOR SIZES
```

followed for all sizes in the data file by the prompt

```
     FOR SIZE xxx
```

where xxx stands for the diameter in inches. Enter the cost in dollars per foot for this size. For instance:

```
     FOR SIZE 8
     ? 19.3
```

The program will then request the data for the next size. Sizes will appear in the order they were entered into the data file. Entering END will let the user exit this loop at any time. The second format for entering cost data enables the user to enter or change a single cost figure.

Function #	Size in.	Price $/ft
PRICE 4	8	19.3

This entry assigns the cost of $19.3 per foot to size 8 inches, in price function 4. Price function 1 contains the default function, while price function 2 contains the default function for cleaning.

(3) ENERGY. This keyword is used to enter the energy cost in dollars per kilowatt-hour. The format is

```
               Energy cost
               $/kWh
     ENERGY     0.083
```

(4) ENR. This keyword is used to multiply a entire price function by a factor. The format is:

```
               Function #   Multiplication factor
     ENR       2            1.08
```

This entry multiplies all cost data in price function 2 by the factor 1.08 and stores the prices in function 2.

(5) INTEREST. When calculating the present worth of pumping cost, the program requires an interest rate. This keyword is used to enter this rate. The format is

```
                    Interest
                       %
INTEREST              7.5
```

(6) YEAR. When calculating the present worth of pumping cost, the program requires the number of years of operation. This keyword is used to enter this time period in years. The format is:

```
             Years
YEARS         25
```

The default number of years is 10.

(7) END. This keyword will terminate the cost data input. Program control will return to the menu of the cost data routine.

d. PRINT COST DATA. The program will print all data that comprise the cost data routine (that is, entered under c. above or retrieved). In particular, a table of all pipe sizes with the prices for the various price functions is printed, followed by energy cost, the interest rate, and the numbers of years used in computing the present worth of pumping cost. Program control then returns to the menu of the cost data routine.

e. STORE COST DATA. When selecting option 3 in the menu, the program will respond with the prompt "ENTER FILE NAME." The user enters the file name. Control will return to the menu of the cost data routine.

f. RETRIEVE COST DATA. This option is accessed from either the first or second menu of the cost data routine (option 2 or option 4, respectively). (See paragraph 28-25a.) Program control returns to the menu of the cost data routine.

28-26. *Optimization Data Input*. Input of the optimization parameters is similar to the data input in the water distribution system analysis part of the program. It is controlled by a set of keywords that are summarized in Table 28-9 and described in detail below. Data are requested with the following prompt:

O. KEYWORD IS (xxx nn) ENTER (KEYWORD) DATA LIST

The O. indicates that the prompt refers to optimization data. At xxx nn appears the present keyword (e.g., GROUP 2). It consists of a word and a numeric value. The format of the input is then

Keyword value1 value2...valuen

or

Keyword value1 Keyword value2...valuen

Table 28-9. Keywords for Optimization
(O. prompt)

END	
GROUP	xx xxx xxx xxx ...
	Group # List of Link #
or	
GROUP	xx ALL xxx xxx
	Group # First Link # Last Link #
or	
GROUP	xx DELETE
	Group #
HWCC	xxx.x
	Coef. for Cleaning
LIMC	x.x
	% of Minimum Cost
LIMP	x.x
	Pressure Increment psi.
LOAD	xx MINIMUM xx.x
	Pattern # Min. Press. psi
or	
LOAD	xx MINIMUM xxx xx.x
	Pattern # Node # Min. Press. psi
or	
LOAD	xx MINIMUM xxx xxx xx.x
	Pattern # First Node Last Node Min. Press. psi.
or	
LOAD	xx OUTPUT xxx xxx.x
	Pattern # Node # Output gpm.
or	
LOAD	xx PUMP xxx xx.x (xx.x)
	Pattern # Link # Time Running % Efficiency %
or	
LOAD	xx RATIO x.xx
	Pattern # Ratio
or	
LOAD	xx RATIO xxx xxx x.xx
	Pattern # First Node # Last Node # Ratio
PRICE	xx xxx xxx xxx ...
	Price Fct. # List of Link #
PRICE	xx ALL xxx xxx
	Price Fct. # First Link # Last Link #
SIZE	xx xx.x xx.x xx.x ...
	Group # List of Sizes in.
or	
SIZE	xx DELETE
	Group #

where value 1 is part of the keyword. For example, the first format

GROUP 2 201 205 203

states that pipes 201, 203, and 205 should be added to group 2. While

GROUP 2 ALL 209 220

says that all previously defined pipes with numbers in the range 209 to 220 should be added to group 2. If data are entered without a keyword, the present keyword (word and numeric value) as displayed in the prompt will be used. The first numeric value after the word is considered part of the keyword. It can be changed only if the keyword is included. In the above example, the value 2 refers to group 2. The entry "217 219 255" would leave the keyword and the group number unchanged. The word ALL serves as a secondary keyword. First and second keywords can be abbreviated with the first four letters. The numeric values behind the keyword must be separated by blanks or by commas. There must be a space or comma between the keyword and the numeric value after the keyword, as well as in front of the second keyword.

a. GROUP. All pipes to be assigned to groups for sizing must already be part of the system when accessing the optimization routine (i.e., at the time option 2 is selected in the program control menu). That is, all pipes to be sized must have previously been entered in the simulation part of the program (i.e., pipe number, beginning and ending node numbers, diameter, length, and friction coefficient were assigned under the keyword PIPE or LINE). The pipe sizes used at the time of data entry are immaterial but should be "reasonable" because the system must be balanced once with these diameters. The Hazen-Williams coefficient should correspond to that of new pipes. The keyword group is used to identify the pipes to be sized. All pipes in the same group will be assigned the same diameter in the optimization. A group can consist of one pipe. The keyword consists of the word GROUP followed by the group number. The format for the keyword is given below.

	Group #	List of pipe numbers
GROUP	2	201 205 203

Pipes 201, 203, and 205 are added to Group 2.

GROUP 2 is the present keyword. (GROU 2 is equivalent.) If the displayed keyword in the prompt is GROU 2, the entry "201 205 203" is equivalent to the previous entry. An alternative format is

	Group #		Pipe #	Pipe #
GROUP	3	ALL	117	128

This statement would assign all pipes with numbers in the range 117 through 128 (inclusive) to group 3. Links in this range which are pumps or PRVs are not affected. Again, the keyword and group number are optional. If the present keyword is GROUP 3, "ALL 117 128" is equivalent to the previous entry. If the group number is to be changed, the total keyword (word and numeric

value) must be included. If the present keyword is not GROUP, the keyword must be included to assign pipes to groups. A pipe can be assigned only to one group. If a pipe is assigned to a group more than once, the last entry will override previous entries. Assigning group number 0 (zero) to a pipe will remove the pipe from the group to which it is presently assigned. For instance, if pipes 128 and 144 were previously assigned to group 3 (or any other group), the entry "GROUP 0 128 44" would eliminate pipes 128 and 144 from the list of pipes to be sized. An example of how pipes can be grouped is given in Figure 28-6. Pipes 221, 231, and 241 could form group 1. Pipes 222 and 233 could form group 2.

b. PRICE. This keyword is used to assign a pipe link to be sized to a specific price function. The price functions are part of the cost data file. An assignment of price function 3 to a pipe link means that the pipe prices of function 3 in the cost data file will be used for this pipe in the calculation of total cost. The keyword consists of the word PRICE followed by the price function number. The format is the same as for the keyword GROUP.

	Function #	List of Pipe Numbers
PRICE	3	201 55 117

This entry would assign pipes 55, 117, and 201 to price function 3. If the present keyword is PRICE and the present price function number is 3, the entry "201 55 117" is equivalent to the previous entry. The use of the word ALL to assign a range of pipe numbers is again available.

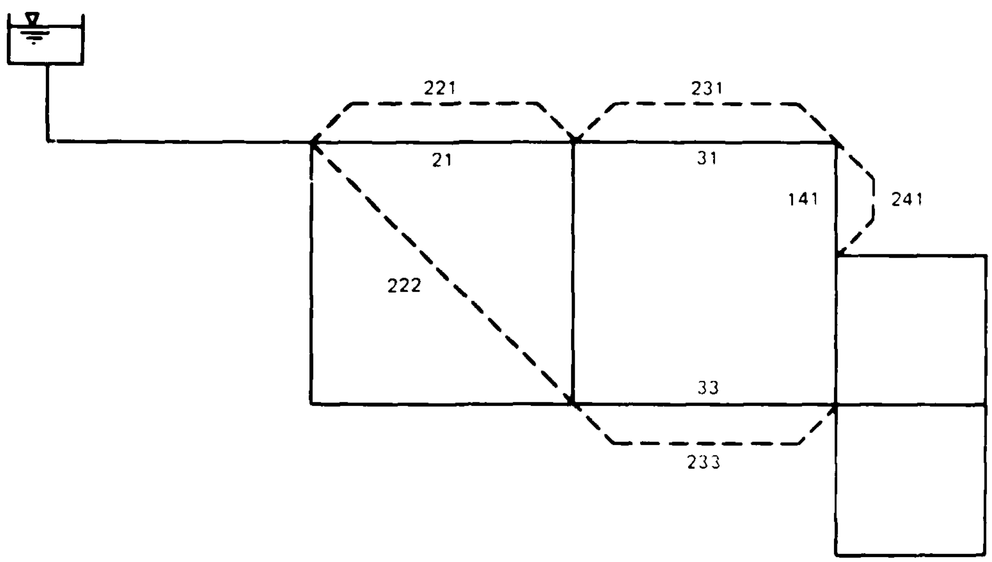

Figure 28-6. Sample system with parallel pipes

	Function #		Pipe #	Pipe #
PRICE	2	ALL	28	44

This entry assigns all pipes with numbers in the range 28 through 44 to price function 2. If the keyword in the prompt is PRICE 2, the first two items are optional. If the price function number needs to be changed, the entry must include the total keyword (word and numeric value). Not all pipes in the same group need to belong to the same price function. Assigning one pipe in a group to a particular price function does not affect any other pipe in the group. If a pipe is assigned more than once to a price function, the last entry will override previous entries. A pipe can be assigned to only one price function. Pipes not assigned to a price function but assigned to a group will default to price function 1. Assigning function number 0 (zero) to a pipe will remove the pipe from any function. For instance, "PRICE 0 114" would eliminate the assigned price function from pipe 114. If no other assignment is made for pipe 114 and this pipe is included in a group, it would default to function 1. If cleaning is an option to adding a new pipe, the cleaning cost of the old pipe will default to price function 2. Price function 2 is the only price function used for cleaning. To indicate that an existing pipe is to be considered for cleaning, the user must enter a parallel new pipe for which one of the possible sizes is C. (See following paragraph.)

c. SIZES. This keyword is used to designate the sizes to be considered during the optimization for a particular group. The keyword consists of the word SIZE followed by a group number. The format is given below.

	Group #	List of Sizes
SIZES	6	10 12 14 16

This entry assigns to group 6 the sizes 10, 12, 14, and 16 inches. If the keyword in the prompt is SIZE 6, "10 12 14 16" is equivalent to the previous entry. The sizes listed must be a subset of the sizes included in the cost data file. Entering a 0 (zero) as a possible size will permit elimination of all pipes in the group as an alternative. Enter a C (for cleaning) if cleaning and lining of the parallel old pipe(s) instead of adding new parallel pipes is to be considered as an alternative. In the case of cleaning as an option, all pipes in the group must have pipes with different pipe numbers but the same beginning and ending nodes which are to be considered for cleaning and are not to be sized. In Figure 28-6, two groups are shown. Group 1 consists of pipes 221, 231, and 241. Existing pipes 21, 31, and 141 are parallel to the three previously listed pipes, respectively. Cleaning and lining of pipes 21, 31, and 141 is permissible. Therefore, listing of C as a size option of group 1 is possible. Group 2 consists of pipes 222 and 233. There is no pipe parallel to 222 (i.e., no pipe has same beginning and ending nodes). For this group, cleaning cannot be specified. An example of size assignments to group 1, which would permit elimination of the group as well as cleaning the existing pipes with the same beginning and ending nodes, would be "SIZES 1 0 C 6 8 10." Within the size range specified, one does not need to list all sizes included in the data file. For instance, "6 10 14" is a legitimate response, even though the cost data file may include 8- and 12-inch pipe sizes as well. Rather than specifying all five sizes from 6 to 14 inches

(6, 8, 10, 12, and 14), the user can specify sizes 6, 10, and 14 in a first run. If the program selects the 12-inch size, the user then could rerun the program for sizes 10, 12, and 14. Since computer time is roughly proportional to the product of the number of sizes in all groups, this procedure may dramatically reduce computer time. However, the procedure may not be equivalent to listing all five sizes in the first run. If the group number needs to be changed, the keyword (word and group number) must be included. If one enters sizes for the same group twice, with (partially) different sets of sizes, the program will use the union of the two (or more) sets. To clear a group from all assigned sizes, enter the word DELETE after the group number. For example, "SIZES 3 DELETE" would clear group 3 of all previously assigned sizes.

d. LOAD. The first loading pattern used in the optimization routine is the one entered in the simulation routine of the program. This keyword is used to assign additional loading patterns. Any assignments made with this keyword start out from the first loading pattern. The keyword consists of the word LOAD followed by the pattern number and then a second keyword. One format is

	Pattern #		Node #	Output (gpm)
LOAD	3	OUTPUT	38	1200

This entry assigns in loading pattern number 3 an output of 1,200 gallons per minute to node 38 regardless of the previous load at this node. OUTPUT is the second keyword in this entry. Input format after the second keyword OUTPUT follows the same format as described in paragraph 28-13e. The last numeric value can be negative (input). Another alternative to this format is

	Pattern #	Ratio	
LOAD	2	RATIO	1.5

If the second keyword is RATIO, the format follows the same format as described in paragraph 28-13p. The above assignment would multiply the output at all nodes by a factor of 1.5. The format

	Pattern		Node #	Node #	Ratio
LOAD	2	RATIO	25	53	1.25

is also available as described in paragraph 28-13p. It would multiply the output at all nodes with numbers in the range 25 through 53 by a factor of 1.25 for loading pattern 2. Any nodes not included in the assignment for a loading pattern will have the same output or input as in loading pattern 1. It is important to remember that when a loading pattern is entered, the program will first set all inputs and outputs to the same value as in pattern 1. Any subsequent changes are to the present loading pattern. For instance, subsequent entries for the same loading pattern of RATIO 1.2 and RATIO 1.5 would result in outputs 1.8 times larger than the values in pattern 1. Entering RATIO 1.2 for loading pattern 2 and RATIO 1.5 for loading pattern 3 would

yield a flow of 1.2 times the load of pattern 1 for pattern 2 and 1.5 times flow in pattern 1 for pattern 3.

e. PUMP. This keyword allows the user to tell the program which pumps should be included in determining energy cost. PUMP is a second keyword used in connection with LOAD. Also entered under this keyword is the percentage of time during which the pump operates and the expected wire-to-water efficiency of the pump. The format for this keyword is shown below.

	Pattern #		Link #	Percent Time Running	Efficiency (%)
LOAD	2	PUMP	109	60	78

This entry causes the pump with link number 109 to be included in the energy cost computation. It is assumed the pump runs 60 percent of the time under load pattern 2 and its wire-to-water efficiency is 78 percent. Pumps not listed under this keyword are assumed to operate according to the characteristic pump curve entered in the simulation part of the program, but their energy costs are not considered in the optimization. Pumps listed under this keyword are assumed to operate with the characteristic curve specified in the simulation part of the program unless continuity dictates the flow rate of the pump (no reservoir or tank on the downstream side of the pump). In this case, the characteristic curve is ignored, and the head is selected such that the minimum pressure requirement downstream of the pump is exactly met.

f. MINIMUM. This is a second keyword used in connection with LOAD. It is used to assign the minimum pressure that is to be maintained at nodes. The format is shown below.

	Min. Pressure (psi)
LOAD 2 MINIMUM	35

This entry assigns a minimum pressure of 35 pounds per square inch to all nodes except constant head nodes for loading pattern 2. An alternative format is

	Node #	Min. Pressure (psi)
LOAD 3 MINIMUM	16	40

This entry assigns a minimum pressure of 40 pounds per square inch to node 16 in loading pattern 3. The third format is

	Node #	Node #	Min. Pressure (psi)
LOAD 1 MINIMUM	28	76	32

This entry assigns a minimum pressure of 32 pounds per square inch to all nodes with numbers in the range 28 through 76 (inclusive) for loading pattern 1. If a minimum pressure is assigned to a constant head node, the

assignment is ignored. If a node is assigned more than one minimum pressure, only the last entry is retained. Nodes that are not assigned a minimum pressure are not checked.

g. LIMC. This keyword lets the user specify a percentage of the (present) minimum cost. If, during the optimization procedure, a solution is encountered which is within this percentage difference from the cost of the current least-cost solution, this solution will be kept in a solution queue of Pareto Optimal solutions, even though it is more expensive than the current best solution, as long as this solution provides a higher pressure than the required minimum. The format is shown below.

	% of Minimum Cost
LIMC	5

This entry would keep any solution in the queue of Pareto Optimal solutions which is not more expensive than 105 percent of the best solution found to this point. The default value is 3 percent.

h. LIMP. This keyword lets the user specify a pressure differential in pounds per square inch. If, during the optimization procedure, a solution is encountered which fails the pressure requirement by less than the specified differential, this solution will be kept in the solution queue of Pareto Optimal solutions as long as the solution offers lower cost. The format is shown below.

	Pressure Differential (psi)
LIMP	3

This entry would keep any solution on file which fails the pressure requirement by less than 3 pounds per square inch. The default value is 3 pounds per square inch.

i. HWCC. This keyword lets the user specify the Hazen-Williams coefficient for pipes that are to be cleaned and lined, if applicable. All pipes in the system to be cleaned will have the same coefficient. The format is shown below.

	Coefficient
HWCC	110

This entry assigns an after-cleaning Hazen-Williams coefficient of 110 to all pipes to be cleaned. The default value is 120.

j. END. This keyword will terminate the data entry routine. Program control returns to the main option menu of the optimization routine.

28-27. Printing of Optimization Data. All optimization data as entered (or retrieved) under paragraph 28-26 are printed when the user selects option 2 in the optimization menu. This output consists of a table that lists the group

number and pipes assigned to the group, the sizes assigned to each group, the loading patterns with the assigned outputs and minimum pressures, the loading patterns with the pump numbers and the percentage of time running under each pattern, and the parameters for the Pareto Optimal solution queue. Control returns to the option menu of the optimization routine.

28-28. Storage and Retrieval of Optimization Data. The optimization parameters (entered and printed as described in paragraphs 28-26 and 28-27) can be stored under a user-selected file name. When selecting option 3 in the optimization menu, the program will respond with the prompt "ENTER FILE NAME." The user enters any file name that conforms with the file name requirements of the computer system. Data stored under this option can be retrieved through option 4 in the menu of the optimization routine.

28-29. Optimization. To perform the optimization the user selects option 0 (zero) or 0E in the menu of the optimization routine. A selection of 0 displays group numbers, diameters, cost, and pressures. Option 0 is based on a percent completeness of the job. A selection of 0E will display combination number, cost, minimum pressure, reason for failure, and pipe diameters for each combination. Selecting 0E is recommended only for systems with few groups and sizes since every combination is printed. The program will determine the least expensive combination of pipe sizes which meets the minimum pressure requirement for each loading pattern. At the same time the program will generate alternate solutions that are Pareto Optimal (or noninferior). It includes solutions that are not more than X percent more expensive than the minimum-cost solution on file at the time the Pareto Optimal solution is encountered. The value of X is specified under the keyword LIMC. Other solutions included are those that have minimum pressures less than specified but within Y pounds per square inch of the permissible minimum. The value of Y is specified under the keyword LIMP. The output will list the optimal solution as well as the queue of Pareto Optimal solutions. Generation of the solution queue will require extra computer time. The program can avoid the generation of the queue (i.e., only select a single optimal solution) by assigning values of 0 (zero) to both X and Y. Pipe diameters of the optimal solution and the outputs of the pattern that generates the lowest pressure are assigned. Program control returns to the menu of the optimization routine. It is then possible to return to program control and simulation in order to balance the optimal system and to view the output.

28-30. Example 2. The network for this example is shown in Figure 28-7. The purpose of the example is to illustrate cost data entry and the entry of the optimization parameters.

a. System Data Input. First the user must enter information using the simulation routine. The input of the system data in the simulation routine is shown. Lines without a question mark are the prompts printed by the program. The user's input appears after the question marks.

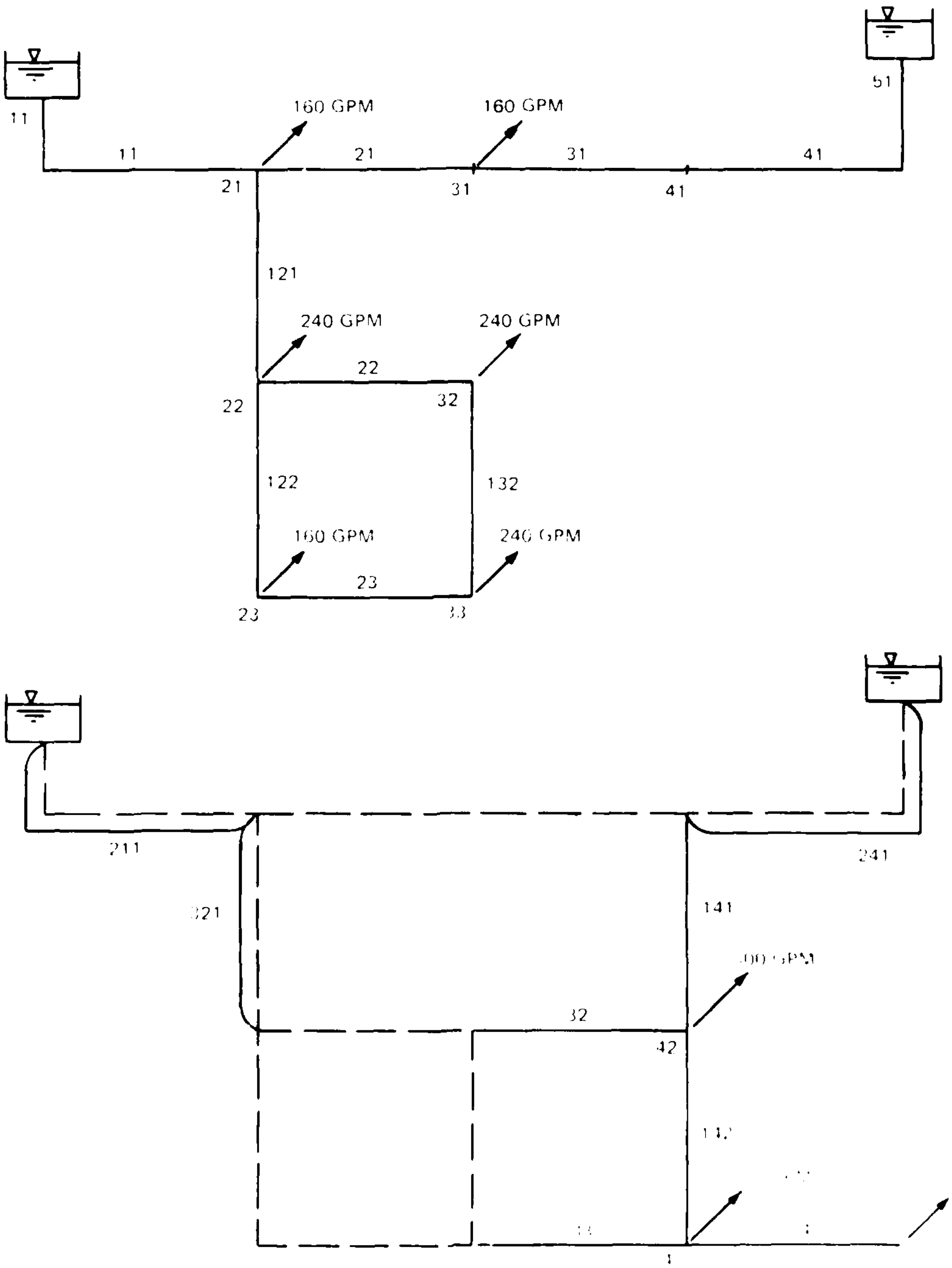

Figure 28-7. System layout, Example 2, before and after expansion

```
PROGRAM CONTROL :
         SIMULATION           : ENTER  1  PRESS RETURN
         OPTIMIZATION         :        2
         COST DATA            :        3
         TIME SIMULATION      :        4
         TERMINATE PROGRAM    :        9

? 1

SIMULATION ROUTINE

SELECT PROGRAM OPTION :

         TO ENTER NEW JOB     : ENTER  1  PRESS RETURN
         TO RETRIEVE DATA     :        2

? 1
S. KEYWORD IS JOB ENTER (KEYWORD) DATA LIST
? EXAMPLE 2
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 11 11 21 14 15840 75
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 21 21 31 10 5280 80
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 22 22 32 8 5280
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 23 23 33 8 5280
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 31 31 41 10 5280 80
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 41 41 51 10 21120 80
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 121 21 22 10 5280 80
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 122 22 23 10 5280 80
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 132 32 33 4 5280
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? NODE
FOR NODE 11 ENTER ELEVATION OUTPUT
? 1200
FOR NODE 21 ENTER ELEVATION OUTPUT
? 1050 160
FOR NODE 22 ENTER ELEVATION OUTPUT
? 980 240
FOR NODE 23 ENTER ELEVATION OUTPUT
? 950 160
FOR NODE 31 ENTER ELEVATION OUTPUT
? 1070 160
FOR NODE 32 ENTER ELEVATION OUTPUT
? 970 240
```

```
FOR NODE 33 ENTER ELEVATION OUTPUT
? 950 240
FOR NODE 41 ENTER ELEVATION OUTPUT
? 1090
FOR NODE 51 ENTER ELEVATION OUTPUT
? 1120
S. KEYWORD IS TANK ENTER (KEYWORD) DATA LIST
? 11 0
S. KEYWORD IS TANK ENTER (KEYWORD) DATA LIST
? 51 100
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? END
```

After the menu appears, select option 2, PRINT INPUT. The node and link table for the input data is shown as Table 28-10. After the data are printed, the user takes option 1, MODIFY SYSTEM, in order to expand the system as shown in Figure 28-7. The dashed lines indicate the existing part of the system; the solid lines, the expansion to be sized. The output on the existing system is to be increased by 25 percent. The outputs on the expansion are shown in Figure 28-7. Note that line 241 is necessary even if the only options for this line are elimination or cleaning/lining of line 41. Entry of the data for system expansion and modification is now continued.

```
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? RATIO 1.25
S. KEYWORD IS RATIO ENTER (KEYWORD) DATA LIST
? PIPE 32 32 42 12 5280 120
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 33 33 43 12 5280 120
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 43 43 53 12 5280 120
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 141 41 42 12 5280 120
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 142 42 43 12 5280 120
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 211 11 21 12 15840 120
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 241 41 51 12 21120 120
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 321 21 22 12 5280 120
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? NODE
FOR NODE 42 ENTER ELEVATION OUTPUT
? 960 300
FOR NODE 43 ENTER ELEVATION OUTPUT
? 960 300
FOR NODE 53 ENTER ELEVATION OUTPUT
? 950 200
S. KEYWORD IS TANK ENTER (KEYWORD) DATA LIST
? END
```

Table 28-10. First Input for Example 2

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXAMPLE 2

NODE NO.	ELEV. FT.	OUTPUT GPM	
11	1200.0		RESERVOIR
21	1050.0	160.	
22	980.0	240.	
23	950.0	160.	
31	1070.0	160.	
32	970.0	240.	
33	950.0	240.	
41	1090.0	0.	
51	1120.0		WATER LEVEL: 100.0

PIPE CONNECTIONS

PIPE NO.	B NODE	E NODE	DIAM. IN.	LENGTH FT.	COEF
11	11	21	14.0	15840.0	75.
21	21	31	10.0	5280.0	80.
22	22	32	8.0	5280.0	100.*
23	23	33	8.0	5280.0	100.*
31	31	41	10.0	5280.0	80.
41	41	51	10.0	21120.0	80.
121	21	22	10.0	5280.0	80.
122	22	23	10.0	5280.0	80.
132	32	33	4.0	5280.0	100.*

In Table 28-11 the input data of the system to be optimized are shown. The optimization routine can be executed only if the system was balanced. So, after printing the input data, option 0 (zero) (BALANCING) is selected. The output is shown in Table 28-12. Note that a diameter of 12 inches was used for all pipes to be sized. This value has no effect on the optimization routine and the final answer. Any value could have been used. Yet, to better evaluate the performance of the system, it is suggested that "reasonable" diameters be used. To terminate the simulation routine, the user takes option 8 in the menu of the simulation routine.

b. Cost Data Input. The user is likely to have the cost data permanently stored in a cost data file under a user-selected name. When this file is to be used, the user must transfer the permanent file to local work space before running the program. From the program control menu:

Table 28-11. Input for Example 2 After Expansion

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXAMPLE 2

NODE NO.	ELEV. FT.	OUTPUT GPM	
11	1200.0		RESERVOIR
21	1050.0	200.	
22	980.0	300.	
23	950.0	200.	
31	1070.0	200.	
32	970.0	300.	
33	950.0	300.	
41	1090.0	0.	
42	960.0	300.	
43	960.0	300.	
51	1120.0		WATER LEVEL: 100.0
53	950.0	200.	

PIPE CONNECTIONS

PIPE NO.	B NODE	E NODE	DIAM. IN.	LENGTH FT.	COEF
11	11	21	14.0	15840.0	75.
21	21	31	10.0	5280.0	80.
22	22	32	8.0	5280.0	100.*
23	23	33	8.0	5280.0	100.*
31	31	41	10.0	5280.0	80.
32	32	42	12.0	5280.0	120.
33	33	43	12.0	5280.0	120.
41	41	51	10.0	21120.0	80.
43	43	53	12.0	5280.0	120.
121	21	22	10.0	5280.0	80.
122	22	23	10.0	5280.0	80.
132	32	33	4.0	5280.0	100.*
141	41	42	12.0	5280.0	120.
142	42	43	12.0	5280.0	120.
211	11	21	12.0	15840.0	120.
241	41	51	12.0	21120.0	120.
321	21	22	12.0	5280.0	120.

Table 28-12. Example 2 After First Output

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXAMPLE 2

NODE DATA Page 1

NODE NO.	ELEV. FT.	OUTPUT GPM	E.G.L. FT.	PR.HEAD FT.	PRESSURE PSI	
11	1200.0	-1195.	1200.0			RESERVOIR
21	1050.0	200.	1180.8	130.8	56.7	
22	980.0	300.	1174.3	194.3	84.2	
23	950.0	200.	1162.5	212.5	92.1	
31	1070.0	200.	1179.4	109.4	47.4	
32	970.0	300.	1164.0	194.0	84.0	
33	950.0	300.	1157.5	207.5	89.9	
41	1090.0		1180.3	90.3	39.1	
42	960.0	300.	1164.2	204.2	88.5	
43	960.0	300.	1157.8	197.8	85.7	
51	1120.0	-1105.	1220.0	100.0	43.3	SUPPLY
53	950.0	200.	1157.0	207.0	89.7	

PIPE DATA

PIPE NO.	NODES FROM	TO	DIAM. IN.	LENGTH FT.	COEF	FLOW GPM	VEL. FT/SEC	HEAD LOSS
11	11	21	14.0	15840.0	75	578.	1.2	19.2
21	21	31	10.0	5280.0	80	112.	.5	1.4
22	22	32	8.0	5280.0	100.*	229.	1.5	10.3
23	23	33	8.0	5280.0	100.*	154.	1.0	5.0
31	41	31	10.0	5280.0	80.	88.	.4	.9
32	42	32	12.0	5280.0	120.	100.	.3	.2
33	43	33	12.0	5280.0	120.	116.	.3	.3
41	51	41	10.0	21120.0	80.	323.	1.3	39.7
43	43	53	12.0	5280.0	120.	200.	.6	.8
121	21	22	10.0	5280.0	80.	258.	1.1	6.6
122	22	23	10.0	5280.0	80.	354.	1.4	11.8
132	32	33	4.0	5280.0	100.*	29.	.7	6.5
141	41	42	12.0	5280.0	120.	1016.	2.9	16.1
142	42	43	12.0	5280.0	120.	617.	1.7	6.4
211	11	21	12.0	15840.0	120.	617.	1.7	19.2
241	51	41	12.0	21120.0	120.	782.	2.2	39.7
321	21	22	12.0	5280.0	120.	625.	1.8	6.6

```
PROGRAM CONTROL :

     SIMULATION        : ENTER  1  PRESS RETURN
     OPTIMIZATION      :        2
     COST DATA         :        3
     TERMINATE PROGRAM :        4
```

the user now selects option 3. The next menu is:

```
SELECT PROGRAM OPTION:

     MODIFY DATA       :  ENTER  1  PRESS RETURN
     PRINT DATA        :         2
     STORE DATA        :         3
     RETRIEVE DATA     :         4
     PROGRAM CONTROL   :         8
     TERMINATE PROGRAM:          9
```

In this example option 1 is selected to show how cost data are entered. The data to be entered are sufficient only to run this example. The item-by-item input is shown below. Lines without a question mark are the prompts printed by the program. The user's responses appear after the question marks.

```
C. KEYWORD IS SIZE ENTER (KEYWORD) DATA LIST
? PRICE 1 6 15.1
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? 8 19.3
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? 10 28.9
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? 12 40.5
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? 14 52.1
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? 16 59.4
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? 2 6 14.5
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? 8 15.7
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? 10 16.8
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? 12 17.7
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? 14 18.5
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? 16 19.2
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? ENERGY 0.075
C. KEYWORD IS ENER ENTER (KEYWORD) DATA LIST
? YEAR 10
```

```
C. KEYWORD IS YEAR ENTER (KEYWORD) DATA LIST
? INTEREST 10
C. KEYWORD IS INTE ENTER (KEYWORD) DATA LIST
? END
```

In the above routine, price function 1 was entered, which is the default cost function for new pipes, and function 2 was entered, which is the default cost function for cleaning/lining existing pipes. After the menu appears, select option 2, PRINT DATA. The cost data table as printed appears in Table 28-13. The last three data items are used only when calculating the present worth of pumping cost. Since this system does not include pumps, these items are not required in order to run the optimization. To terminate the cost data routine the user takes option 8 in the menu of the cost data routine.

c. Optimization Parameters. At this point the balanced system data and cost data are entered. From the program control menu the user now takes option 2, OPTIMIZATION. The program responds with the menu of the optimization routine. Selection of the optimization parameters in this example is based on the following considerations. The new demands require reinforcement of either line 11 or 41. Considering the low Hazen-Williams coefficients of these lines, cleaning and lining should be considered as an alternative to adding new parallel pipes. Because of the distance from node 11 to the new area, line 321 is also added as part of the reinforcement in this part of the system. Lines 211 and 321 form group 1. Line 241 forms group 2. Lines 141 and 142 are to have the same diameter and form group 3. Lines 32 and 33 are put into group 4, while line 43 forms group 5. All new lines are assigned to price function 1 (default for new pipes), and pipes 11 and 41 are assigned to price function 2 (default for cleaning). To illustrate the assigning to price function, the assignment will be done explicitly, even though it would not be necessary, since the pipes would automatically default to these functions. The Hazen-Williams coefficient for the cleaned pipes is entered as 120 (again in case of no assignment, the program would default to this value). Input of data is shown below, starting at the point after option 1 was selected in the menu of the optimization routine.

```
O. KEYWORD IS (GROU 1) ENTER (KEYWORD) DATA LIST
? 211 321
O. KEYWORD IS (GROU 2) ENTER (KEYWORD) DATA LIST
? GROUP 2 241
O. KEYWORD IS (GROU 3) ENTER (KEYWORD) DATA LIST
? GROUP 3 141 142
O. KEYWORD IS (GROU 4) ENTER (KEYWORD) DATA LIST
? GROUP 4 32 33
O. KEYWORD IS (GROU 5) ENTER (KEYWORD) DATA LIST
? GROUP 5 43
O. KEYWORD IS (GROU 6) ENTER (KEYWORD) DATA LIST
? SIZE 1 0 C 12 14 16
O. KEYWORD IS (SIZE 2) ENTER (KEYWORD) DATA LIST
? SIZE 2 0 C 12 14 16
O. KEYWORD IS (SIZE 3) ENTER (KEYWORD) DATA LIST
? SIZE 3 8 10 12
```

```
0. KEYWORD IS (SIZE 4) ENTER (KEYWORD) DATA LIST
? SIZE 4 6 8 10
0. KEYWORD IS (SIZE 5) ENTER (KEYWORD) DATA LIST
? SIZE 5 6 8 10 12
0. KEYWORD IS (SIZE 6) ENTER (KEYWORD) DATA LIST
? PRICE 1 32 33 43 141 142 211 241 321
0. KEYWORD IS (PRIC 1) ENTER (KEYWORD) DATA LIST
? PRICE 2 11 41
0. KEYWORD IS (PRIC 2) ENTER (KEYWORD) DATA LIST
? HWCC 120
0. KEYWORD IS (HWCC)  ENTER (KEYWORD) DATA LIST
?
```

Table 28-13. Cost Data

	PRICE FUNCTIONS	
SIZE	1	2
2.0	6.3	30.0
3.0	8.6	30.0
4.0	10.8	30.0
6.0	15.1	14.5
8.0	19.3	15.7
10.0	28.9	16.8
12.0	40.5	17.7
14.0	52.1	18.5
16.0	59.4	19.2
18.0	68.6	20.0
20.0	80.1	20.5
24.0	106.0	21.6
30.0	147.0	23.1
36.0	192.0	24.3
42.0	242.0	25.4
48.0	295.0	26.4
54.0	331.0	0.0
60.0	396.0	0.0
66.0	477.0	0.0
72.0	554.0	0.0
78.0	642.0	0.0
84.0	734.0	0.0
96.0	941.0	0.0
108.0	1170.0	0.0
120.0	1420.0	0.0

ENERGY COST 0.075 $/KWH

TIME PERIOD 10 YEARS

INTEREST 10.0%

As indicated above, the last three entries are not necessary. The program would default to these values. The loading patterns will be specified next. Under the loads entered in the simulation routine the required pressure is 50 pounds per square inch at all nodes, except nodes 21, 31, and 41 where pressures of 40, 25, and 25 pounds per square inch, respectively, are acceptable. In a second loading pattern a fire load of 1,000 gallons per minute is to be added at node 32 for a total output of 1,300 gallons per minute. A minimum pressure of 20 pounds per square inch is to be maintained throughout the system except at the location of the fire load, where 15 pounds per square inch is acceptable. In the third loading pattern a fire load of 600 gallons per minute is added at node 53 for a total output of 800 gallons per minute. Again, pressures should be larger than 20 pounds per square inch, except at node 53 where 15 pounds per square inch is acceptable. Data entry is now continued.

```
 LOAD 1 MINI 50
0. KEYWORD IS (LOAD 1) ENTER (KEYWORD) DATA LIST
? MINI 21 40
0. KEYWORD IS (LOAD 1) ENTER (KEYWORD) DATA LIST
? MINI 31 25
0. KEYWORD IS (LOAD 1) ENTER (KEYWORD) DATA LIST
? MINI 41 25
0. KEYWORD IS (LOAD 1) ENTER (KEYWORD) DATA LIST
? LOAD 2 OUTPUT 32 1300
0. KEYWORD IS (LOAD 2) ENTER (KEYWORD) DATA LIST
? MINI 20
0. KEYWORD IS (LOAD 2) ENTER (KEYWORD) DATA LIST
? MINI 32 15
0. KEYWORD IS (LOAD 2) ENTER (KEYWORD) DATA LIST
? LOAD 3 OUTPUT 53 800
0. KEYWORD IS (LOAD 3) ENTER (KEYWORD) DATA LIST
? MINI 20
0. KEYWORD IS (LOAD 3) ENTER (KEYWORD) DATA LIST
? MINI 53 15
0. KEYWORD IS (LOAD 3) ENTER (KEYWORD) DATA LIST
? END
```

The program returns to the option menu. When taking option 2, PRINT OPT. DATA, the program prints all the data as entered (or the default values if data were not entered). This output is reproduced in Table 28-14. The optimization data as entered in this paragraph can be stored with option 3. Then, at a later time, the data could be retrieved under option 4 for editing to be used in another optimization run. Data stored here are limited to the optimization parameters only as printed under option 2. The system data and cost data are not part of the data stored here.

Table 28-14. Optimization Parameters

OPTIMIZATION PARAMETERS

GROUP ASSIGNMENTS

PIPES IN GROUP 1 :
211 321

PIPES IN GROUP 2 :
241

PIPES IN GROUP 3 :
141 142

PIPES IN GROUP 4 :
32 33

PIPES IN GROUP 5 :
43

PRICE FUNCTION ASSIGNMENTS

PIPES IN PRICE FCT. 1 :
32 33 43 141 142 211 241 321

SIZE ASSIGNMENTS

GROUP #	SIZES ASSIGNED:				
1	E	12.0	14.0	16.0	C
2	E	12.0	14.0	16.0	C
3	8.0	10.0	12.0		
4	6.0	8.0	10.0		
5	6.0	8.0	10.0	12.0	

LOADING PATTERNS

		LOADS IN GPM	AND	MIN. PRESSURE	IN PSI		
PATTERN #		1	*	2	*	3	*
NODE #	*	GPM	PSI*	GPM	PSI*	GPM	PSI*
21	*	200.	40.0*	200.	20.0*	200.	20.0*
22	*	300.	50.0*	300.	20.0*	300.	20.0*
23	*	200.	50.0*	200.	20.0*	200.	20.0*
31	*	200.	25.0*	200.	20.0*	200.	20.0*
32	*	300.	50.0*	1300.	15.0*	300.	20.0*
33	*	300.	50.0*	300.	20.0*	300.	20.0*
41	*	0.	25.0*	0.	20.0*	0.	20.0*
42	*	300.	50.0*	300.	20.0*	300.	20.0*
43	*	300.	50.0*	300.	20.0*	300.	20.0*
53	*	200.	50.0*	200.	20.0*	800.	15.0*

COEF. FOR CLEANING 120.0
PRESSURE TOLERANCE -3. PSI
COST TOLERANCE +3. %

d. Executing the Optimization Routine. The user now can take option 0, OPTIMIZE. The program will respond with printing the following information:

```
IN GROUP 5:  SIZE 6.0 ELIMINATED
IN GROUP 2:  SIZE 0.0 ELIMINATED
IN GROUP 2:  CLEANING ELIMINATED

 GROUP 1,  # OF SIZES:  5
 GROUP 2,  # OF SIZES:  3
 GROUP 3,  # OF SIZES:  3
 GROUP 4,  # OF SIZES:  3
 GROUP 5,  # OF SIZES:  3

     405 COMBINATIONS WILL BE TESTED.

JOB IS 10. % COMPLETE
 BEST SOLUTION:
     GROUP       1      2      3      4      5
     DIAM.       E    14.0   12.0   10.0   12.0
     AT COST OF        2047056.
     MIN. PRESSURE           1.6

JOB IS 20. % COMPLETE
 BEST SOLUTION:
     GROUP       1      2      3      4      5
     DIAM.       E    14.0   12.0   8.0   12.0
     AT COST OF        1945680.
     MIN. PRESSURE           2.1

JOB IS 30. % COMPLETE
 BEST SOLUTION:
     GROUP       1      2      3      4      5
     DIAM.       E    14.0   12.0   8.0   12.0
     AT COST OF        1945680.
     MIN. PRESSURE           2.1

JOB IS 40. % COMPLETE
 BEST SOLUTION:
     GROUP       1      2      3      4      5
     DIAM.       E    14.0   12.0   8.0   12.0
     AT COST OF        1945680.
     MIN. PRESSURE           2.1

JOB IS 50. % COMPLETE
 BEST SOLUTION:
     GROUP       1      2      3      4      5
     DIAM.       E    14.0   12.0   8.0   10.0
     AT COST OF        1884432.
     MIN. PRESSURE           2.1
```

```
JOB IS 60. % COMPLETE
 BEST SOLUTION:
     GROUP      1      2      3      4     5
     DIAM.         E   14.0   12.0   8.0  10.0
     AT COST OF       1884432.
     MIN. PRESSURE          2.1

JOB IS 70. % COMPLETE
 BEST SOLUTION:
     GROUP      1      2      3      4     5
     DIAM.         E   14.0   12.0   8.0  10.0
     AT COST OF       1884432.
     MIN. PRESSURE          2.1

JOB IS 80. % COMPLETE
 BEST SOLUTION:
     GROUP      1      2      3      4     5
     DIAM.         E   14.0   12.0   8.0   8.0
     AT COST OF       1833744.
     MIN. PRESSURE          2.1

JOB IS 90. % COMPLETE
 BEST SOLUTION:
     GROUP      1      2      3      4     5
     DIAM.         E   14.0   12.0   8.0   8.0
     AT COST OF       1833744.
     MIN. PRESSURE          2.1

  OPTIMUM SOLUTION:

GROUP      1      2      3      4      5
DIAM.         E   14.0   12.0   8.0    8.0
AT COST OF       1833744.
MIN. PRESSURE          2.1
IN PATTERN             2

  ALTERNATIVE SOLUTIONS:

DIAM.               E    14.0   12.0   8.0   10.0
MIN.PR.        2.1 IN PATTERN       2 COST     1884432.
```

The program first lists the sizes eliminated. With these sizes the pressure requirement cannot be met, even if all other sizes are kept at their maxima assigned. Then, a list of all groups with the number of sizes to be tested in the group is printed. Then, the total number of combinations to be considered is given. The program will not necessarily compute the flow and pressure distribution for all these combinations. Some combinations are eliminated because of their cost. Other ones can be eliminated because the pipe sizes are too small, as judged by earlier combinations which failed the pressure requirement. As the program eliminates combinations, it lists the percent completeness of the optimizing process and the best combination (so far) of

pipe sizes. The program then lists the pipe sizes by group for the optimum solution, its cost, and the smallest pressure increment by which the allowable minimum pressure is exceeded at any node to be tested for pressure. The alternate solution is Pareto Optimal, i.e., it offers better pressure at increased cost. The program returns to the menu of the optimization routine. The user can now take option 8, PROGRAM CONTROL, followed by option 1, SIMULATION, in the program control menu. The user can balance the system once more. Note that the program automatically assigns the optimal diameters and the most critical loading pattern. The resulting simulation output is reproduced in Table 28-15.

28-31. Example 3. The network for this example is shown in Figure 28-8. The purpose of this example is to illustrate inclusion of pumps into the optimization. In this case flow continuity in the network dictates the flow rate through the pump. During the optimization the program will ignore the characteristic curve of the pump. It will select the pump head in each loading pattern such that the lowest pressure on the downstream side of the pump is equal to the permissible minimum.

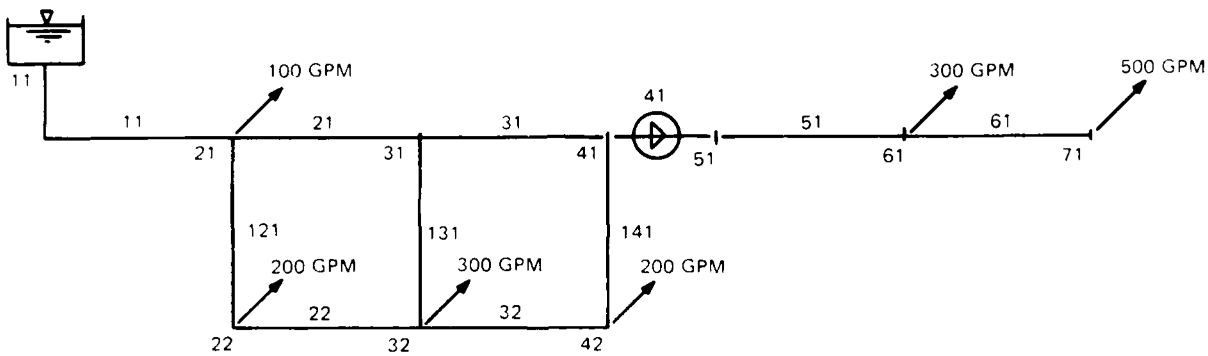

Figure 28-8. System layout, Example 3

a. System Data. The system data are entered through the simulation routine. For the pump, the default characteristic curve will be used with a rated discharge of 800 gallons per minute and a head of 300 feet. The line-by-line prompts and inputs are given below. Lines without a question mark are the prompts. The user's input appears after the question marks.

```
PROGRAM CONTROL :

     SIMULATION          : ENTER  1  PRESS RETURN
     OPTIMIZATION        :        2
     COST DATA           :        3
     TERMINATE PROGRAM   :        9

? 1

SIMULATION ROUTINE
```

Table 28-15. Example 2, Final Output

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXAMPLE 2

NODE DATA   Page 1

NODE NO.	ELEV. FT.	OUTPUT GPM	E.G.L. FT.	PR.HEAD FT.	PRESSURE PSI	
11	1200.0	-1123.	1200.0			RESERVOIR
21	1050.0	200.	1134.5	84.5	36.6	
22	980.0	300.	1059.5	79.5	34.5	
23	950.0	200.	1055.8	105.8	45.8	
31	1070.0	200.	1134.7	64.7	28.0	
32	970.0	1300.	1020.2	50.2	21.7	
33	950.0	300.	1155.8	105.8	45.9	
41	1090.0		1140.5	50.5	21.9	
42	960.0	300.	1087.2	127.2	55.1	
43	960.0	300.	1074.8	114.8	49.7	
51	1120.0	-2177.	1220.0	100.0	43.3	SUPPLY
53	950.0	200.	1069.1	119.1	51.6	

PIPE DATA

PIPE NO.	NODES FROM	TO	DIAM. IN.	LENGTH FT.	COEF	FLOW GPM	VEL. FT/SEC	HEAD LOSS
11	11	21	14.0	15840.0	75	1123.	2.3	65.5
21	21	31	10.0	5280.0	80	40.	.2	.2
22	22	32	8.0	5280.0	100.*	472.	3.0	39.4
23	23	33	8.0	5280.0	100.*	10.	.1	.0
31	41	31	10.0	5280.0	80.	240.	1.0	5.7
32	42	32	8.0	5280.0	120.	755.	4.8	67.0
33	43	33	8.0	5280.0	120.	382.	2.4	19.0
41	51	41	10.0	21120.0	80.	470.	1.9	79.5
43	43	53	8.0	5280.0	120.	200.	1.3	5.7
121	21	22	10.0	5280.0	80.	963.	3.9	75.0
122	22	23	10.0	5280.0	80.	190.	.8	3.7
132	32	33	4.0	5280.0	100.*	72.	1.8	35.7
141	41	42	12.0	5280.0	120.	1937.	5.5	53.2
142	42	43	12.0	5280.0	120.	882.	2.5	12.4
211	11	21	.0	15840.0	120.	0.	R	65.5
241	51	41	14.0	21120.0	120.	1707.	3.6	79.5
321	21	22	.0	5280.0	120.	0.	R	75.0

```
SELECT PROGRAM OPTION :
     TO ENTER NEW JOB    : ENTER  1  PRESS RETURN
     TO RETRIEVE DATA    :        2

? 1
S. KEYWORD IS JOB ENTER (KEYWORD) DATA LIST
? EXAMPLE 3
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 11 11 21 16 10560
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 21 21 31 14 5280
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 22 22 32 8 5280
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 31 31 41 14 5280
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 32 32 42 8 5280
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 51 51 61 8 5280
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 61 61 71 8 5280
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 121 21 22 8 5280
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 131 31 32 6 5280
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 141 41 42 8 5280
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? PUMP 41 41 51
POINT 1 ON CHARACTERISTIC CURVE:  ENTER DISCHARGE, HEAD
? 800 300
POINT 2 ON CHARACTERISTIC CURVE:  ENTER DISCHARGE, HEAD
? E
S. KEYWORD IS PUMP ENTER (KEYWORD) DATA LIST
? NODE
FOR NODE 11 ENTER ELEVATION OUTPUT
? 1000
FOR NODE 21 ENTER ELEVATION OUTPUT
? 800 100
FOR NODE 22 ENTER ELEVATION OUTPUT
? 800 200
FOR NODE 31 ENTER ELEVATION OUTPUT
? 800
FOR NODE 32 ENTER ELEVATION OUTPUT
? 780 300
FOR NODE 41 ENTER ELEVATION OUTPUT
? 800
FOR NODE 42 ENTER ELEVATION OUTPUT
? 780 1200
```

```
FOR NODE 51 ENTER ELEVATION OUTPUT
? 800
FOR NODE 61 ENTER ELEVATION OUTPUT
? 980 300
FOR NODE 71 ENTER ELEVATION OUTPUT
? 950 500
S. KEYWORD IS TANK ENTER (KEYWORD) DATA LIST
? 11.0
S. KEYWORD IS TANK ENTER (KEYWORD) DATA LIST
? END
```

The input data are shown in Table 28-16.

The pipe diameters are arbitrary but "reasonable." All pipes are to be sized, except pipe 131 which has a fixed diameter of 6 inches. The output at node 42 is 200 gallons per minute plus a fire flow of 1,000 gallons per minute. After data entry the system is balanced. The corresponding output is shown in Table 28-17.

b. Cost Data. The input of the cost data follows the same format as used and illustrated in Example 2. After the system data are entered and the system is balanced once, the user returns to the PROGRAM CONTROL by taking option 8. From the program control menu

```
PROGRAM CONTROL:

     SIMULATION         : ENTER  1 PRESS RETURN
     OPTIMIZATION       :        2
     COST DATA          :        3
     TERMINATE PROGRAM  :        4
```

the user selects option 3. The next menu is

```
SELECT PROGRAM OPTION:
          MODIFY DATA      :  ENTER  1  PRESS RETURN
          PRINT DATA       :         2
          STORE DATA       :         3
          RETRIEVE DATA    :         4
          PROGRAM CONTROL  :         8
          TERMINATE PROGRAM:         9
```

Option 1 is selected. Only price function 1 will be entered, as well as energy cost, time period, and interest rate.

```
C. KEYWORD IS SIZE ENTER (KEYWORD) DATA LIST
? PRICE 1 6 15.1
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? 8 19.3
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? 10 28.9
```

Table 28-16. Input Data for Example 3

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXAMPLE 3

NODE NO.	ELEV. FT.	OUTPUT GPM	
11	1000.0		RESERVOIR
21	800.0	100.	
22	800.0	200.	
31	800.0	0.	
32	780.0	300.	
41	800.0	0.	
42	780.0	1200.	
51	800.0	0.	
61	980.0	300.	
71	950.0	500.	

PIPE CONNECTIONS

PIPE NO.	B NODE	E NODE	DIAM. IN.	LENGTH FT.	H-W C	
11	11	21	16.0	10560.0	100.*	
21	21	31	14.0	5280.0	100.*	
22	22	32	8.0	5280.0	100.*	
31	31	41	14.0	5280.0	100.*	
32	32	42	8.0	5280.0	100.*	
41	41	51				PUMP
51	51	61	8.0	5280.0	100.*	
61	61	71	8.0	5280.0	100.*	
121	21	22	8.0	5280.0	100.*	
131	31	32	6.0	5280.0	100.*	
141	41	42	8.0	5280.0	100.*	

PUMP COEFFICIENTS FOR PUMP 41

Q*Q	Q	CONSTANT
-31.4761	-.0017	400.0

Table 28-17. First Output for Example 3

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXAMPLE 3

NODE DATA Page 1

NODE NO.	ELEV. FT.	OUTPUT GPM	E.G.L. FT.	PR.HEAD FT.	PRESSURE PSI	
11	1000.0	-2600.	1000.0			RESERVOIR
21	800.0	100.	936.6	136.6	59.2	
22	800.0	200.	865.5	65.5	28.4	
31	800.0		904.3	104.3	45.2	
32	780.0	300.	829.6	49.6	21.5	
41	800.0		881.4	81.4	35.2	
42	780.0	1200.	791.6	11.6	5.0	
51	800.0		1181.4	381.4	165.2	
61	980.0	300.	1076.9	96.9	42.0	
71	950.0	500.	1033.1	83.1	36.0	

PIPE DATA

PIPE NO.	NODES FROM	NODES TO	DIAM. IN.	LENGTH FT.	COEF	FLOW GPM	VEL. FT/SEC	HEAD LOSS
11	11	21	16.0	10560.0	100.*	2600.	4.1	63.4
21	21	31	14.0	5280.0	100.*	1850.	3.9	32.3
22	22	32	8.0	5280.0	100.*	450.	2.9	36.0
31	31	41	14.0	5280.0	100.*	1537.	3.2	22.9
32	32	42	8.0	5280.0	100.*	463.	3.0	38.0
41	41	51	PUMP HEAD	300.0	FT	800.	POWER	61. HP
51	51	61	8.0	5280.0	100.*	800.	5.1	104.5
61	61	71	8.0	5280.0	100.*	500.	3.2	43.7
121	21	22	8.0	5280.0	100.*	650.	4.1	71.1
131	31	32	6.0	5280.0	100.*	313.	3.6	74.7
141	41	42	8.0	5280.0	100.*	737.	4.7	89.7

```
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? 12 40.5
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? 14 52.1
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? 16 59.4
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? 18 68.6
C. KEYWORD IS PRIC ENTER (KEYWORD) DATA LIST
? 20 80.1
FOR SIZE 24.
? 106
C. KEYWORD IS SIZE ENTER (KEYWORD) DATA LIST
? ENERGY 0.075
C. KEYWORD IS ENER ENTER (KEYWORD) DATA LIST
? YEAR 10
C. KEYWORD IS YEAR ENTER (KEYWORD) DATA LIST
? INTEREST 10
C. KEYWORD IS INTE ENTER (KEYWORD) DATA LIST
? END
```

The cost data can then be printed by taking the appropriate option in the option menu of the cost data routine. The table printed in this routine is shown as Table 28-18.

c. Optimization Parameters. Pipe 11 is to form group 1. Diameters of 14, 16, and 18 inches are to be tried. Pipes 21 and 31 together form group 2. Diameters of 12, 14, and 16 inches are to be tried. Group 3 is to include the four pipes 121, 22, 32, and 141, with diameters including 6, 8, and 10 inches. Pipe 51 forms group 4, and pipe 61 forms group 5. Both groups are assigned pipe sizes 6, 8, and 10 inches. Three loading patterns are to be tested. In the first pattern no fire flow is to be included and a minimum pressure of 50 pounds per square inch must be maintained. This pattern is typical of how the pump operates 50 percent of the time. In pattern 2 the water use is 70 percent of that in pattern 1. Again, a pressure of 50 pounds per square inch must be maintained at all times. This pattern is typical of how the pump is operated 50 percent of the time. In the third pattern the output at node 42 includes the fire load, for a total of 1,200 gallons per minute. Pressures to be maintained are at least 20 pounds per square inch, except at node 42 where 15 pounds per square inch is acceptable. Input of the optimization parameters follows the same format as illustrated in Example 2. The only new aspects are specification of the pump parameters. This input is shown below, following the last prompt after specifying the minimum pressure for loading pattern 3.

```
O. KEYWORD IS LOAD 3 ENTER (KEYWORD) DATA LIST
? LOAD 1 PUMP 41 50 80
O. KEYWORD IS LOAD 1 ENTER (KEYWORD) DATA LIST
? LOAD 2 PUMP 41 50
O. KEYWORD IS LOAD 2 ENTER (KEYWORD) DATA LIST
? END
```

Table 28-18. Cost Data for Example 3

SIZE	PRICE FUNCTIONS 1	2
2.0	6.3	30.0
3.0	8.6	30.0
4.0	10.8	30.0
6.0	15.1	14.5
8.0	19.3	15.7
10.0	28.9	16.8
12.0	40.5	17.7
14.0	52.1	18.5
16.0	59.4	19.2
18.0	68.6	20.0
20.0	80.1	20.5
24.0	106.0	21.6
30.0	147.0	23.1
36.0	192.0	24.3
42.0	242.0	25.4
48.0	295.0	26.4
54.0	331.0	0.0
60.0	396.0	0.0
66.0	477.0	0.0
72.0	554.0	0.0
78.0	642.0	0.0
84.0	734.0	0.0
96.0	941.0	0.0
108.0	1170.0	0.0
120.0	1420.0	0.0

ENERGY COST 0.075 $/KWH

TIME PERIOD 10 YEARS

INTEREST 10.0%

Note that for loading pattern 3 no percentage for time running was specified for pump 41. The program defaults to zero percent, i.e., no pump cost will be included for this pattern since fire flow only occurs for a very small percentage of the time. In determining the total cost, the program will include the pipe cost as well as the cumulative present worth of the pumping cost, according to the percentage of time running under each loading pattern. In Table 28-19 the table of the optimization parameters is shown as printed under the print option of the optimization routine. After taking option 0 (zero) in the menu of the optimization routine, the program will print the following output:

```
IN GROUP 3:  SIZE 6.0 ELIMINATED

GROUP 1,  # OF SIZES:  3
GROUP 2,  # OF SIZES:  3
GROUP 3,  # OF SIZES:  2
GROUP 4,  # OF SIZES:  3
GROUP 5,  # OF SIZES:  3
     162 COMBINATIONS WILL BE TESTED.

JOB IS 10. % COMPLETE.
 BEST SOLUTION:
      GROUP      1       2       3       4       5
      DIAM.   18.0    14.0     8.0     8.0     8.0
      AT COST OF       2026880.
      MIN. PRESSURE            2.2

JOB IS 20. % COMPLETE.
 BEST SOLUTION:
      GROUP      1       2       3       4       5
      DIAM.   18.0    14.0     8.0     8.0     8.0
      AT COST OF       2026880.
      MIN. PRESSURE            2.2

JOB IS 30. % COMPLETE.
 BEST SOLUTION:
      GROUP      1       2       3       4       5
      DIAM.   18.0    14.0     8.0     8.0     8.0
      AT COST OF       2026880.
      MIN. PRESSURE            2.2

JOB IS 40. % COMPLETE.
 BEST SOLUTION:
      GROUP      1       2       3       4       5
      DIAM.   18.0    14.0     8.0     8.0     8.0
      AT COST OF       2026880.
      MIN. PRESSURE            2.2
```

Table 28-19. Optimization Parameters for Example 3

```
OPTIMIZATION PARAMETERS

GROUP ASSIGNMENTS

PIPES IN GROUP    1 :
11
PIPES IN GROUP    2 :
 21  31
PIPES IN GROUP    3 :
 22  32 121 141
PIPES IN GROUP    4 :
 51
PIPES IN GROUP    5 :
 61

PRICE FUNCTION ASSIGNMENTS

PIPES IN PRICE FCT.    1 :
 11  21  22  31  32  51  61  121 141

SIZE ASSIGNMENTS

GROUP #     SIZES ASSIGNED:
    1    18.0  16.0  14.0
    2    16.0  14.0  12.0
    3    10.0   8.0   6.0
    4    10.0   8.0   6.0
    5    10.0   8.0   6.0

LOADING PATTERNS

                  LOADS IN GPM  AND  MIN. PRESSURE IN PSI
PATTERN #          1      *         2      *         3      *
NODE # *   GPM     PSI*   GPM     PSI*   GPM     PSI*
  21   *   100.   50.0*    70.   50.0*   100.   20.0*
  22   *   200.   50.0*   140.   50.0*   200.   20.0*
  31   *     0.   50.0*     0.   50.0*     0.   20.0*
  32   *   300.   50.0*   210.   50.0*   300.   20.0*
  41   *     0.   50.0*     0.   50.0*     0.   20.0*
  42   *   200.   50.0*   140.   50.0*  1200.   15.0*
  51   *     0.   50.0*     0.   50.0*     0.   20.0*
  61   *   300.   50.0*   210.   50.0*   300.   20.0*
  71   *   500.   50.0*   350.   50.0*   500.   20.0*

                  PUMP EFFICIENCY %  AND  % TIME RUNNING
PATTERN #                      1 *         2  *          3  *
PUMP #  EFFIC.                   *            *             *
  41   * 80.0     *        50.0 *       50.0 *          .0 *
COEF. FOR CLEANING 120.
PRESSURE TOLERANCE -3. PSI
COST TOLERANCE     +3. %
```

```
JOB IS 50. % COMPLETE.
 BEST SOLUTION:
      GROUP      1       2       3       4       5
      DIAM.    16.0    12.0    10.0     8.0     8.0
      AT COST OF        2020657.
      MIN. PRESSURE             1.6

JOB IS 60. % COMPLETE.
 BEST SOLUTION:
      GROUP      1       2       3       4       5
      DIAM.    16.0    12.0    10.0     8.0     8.0
      AT COST OF        2020657.
      MIN. PRESSURE             1.6

JOB IS 70. % COMPLETE.
 BEST SOLUTION:
      GROUP      1       2       3       4       5
      DIAM.    16.0    12.0    10.0     8.0     8.0
      AT COST OF        2020657.
      MIN. PRESSURE             1.6

JOB IS 80. % COMPLETE.
 BEST SOLUTION:
      GROUP      1       2       3       4       5
      DIAM.    16.0    12.0    10.0     8.0     8.0
      AT COST OF        2020657.
      MIN. PRESSURE             1.6

JOB IS 90. % COMPLETE.
 BEST SOLUTION:
      GROUP      1       2       3       4       5
      DIAM.    16.0    12.0    10.0     8.0     8.0
      AT COST OF        2020657.
      MIN. PRESSURE             1.6

 PUMPS WITH UNSPECIFIED CHARACTERISTIC CURVE:
 PUMP #      41 FLOW  801. HEAD   294.8

 OPTIMUM SOLUTION:

GROUP      1       2       3       4       5
DIAM.    16.0    12.0    10.0     8.0     8.0
AT COST OF        2020657.
MIN. PRESSURE             1.6
IN PATTERN                3

 PRESENT WORTH OF PUMPING COST      151537
 CHARACTERISTIC CURVES MUST BE ASSIGNED TO PUMPS LISTED ABOVE
 BEFORE RUNNING SIMULATION AGAIN.
```

```
 ALTERNATIVE SOLUTIONS:

DIAM.     18.0  14.0   8.0   8.0   8.0
MIN.PR.    2.2  IN PATTERN      3  COST    2026879.

DIAM.     18.0  14.0   8.0  10.0   8.0
MIN.PR.    2.2  IN PATTERN      3  COST    2041637.

DIAM.     18.0  14.0   8.0   8.0  10.0
MIN.PR.    2.2  IN PATTERN      3  COST    2072327.

DIAM.     16.0  12.0  10.0  10.0   8.0
MIN.PR.    1.6  IN PATTERN      3  COST    2035448.

DIAM.     16.0  12.0  10.0   8.0  10.0
MIN.PR.    1.6  IN PATTERN      3  COST    2066137.

DIAM.     16.0  12.0  10.0  10.0  10.0
MIN.PR.    1.6  IN PATTERN      3  COST    2080896.

DIAM.     16.0  16.0   8.0   8.0   8.0
MIN.PR.   -1.9  IN PATTERN      3  COST    2007309.

DIAM.     16.0  16.0   8.0  10.0   8.0
MIN.PR.   -1.9  IN PATTERN      3  COST    2022077.

DIAM.     16.0  16.0   8.0   8.0  10.0
MIN.PR.   -1.9  IN PATTERN      3  COST    2052786.

DIAM.     16.0  16.0   8.0  10.0  10.0
MIN.PR.   -1.9  IN PATTERN      3  COST    2067544.
```

As indicated in the printout above it will be necessary to assign a characteristic curve to pump 41 since the curve entered in the simulation is no longer appropriate. The printout indicates the discharge and head required. From the menu of the optimization routine the user takes option 8 in order to return to the program control menu. Then option 1, SIMULATION, is selected. In the menu of the simulation routine, option 1 is used to enter the characteristic curve (default curve for a rated discharge of 800 gallons per minute and a head of 294.9 feet). The final output after balancing is shown in Table 28-20.

28-32. Example 4. The purpose of this example is to show how cost of a pump with fixed characteristic curve can be included in the optimization. In Figure 28-9 the layout of the system is shown. It has three supply points, two tanks, and a pump, pumping from a reservoir into the system. Unrestricted optimization, including the elimination of certain pipes as options, would certainly result in the elimination of the loop. Grouping and size ranges are used to prevent the optimization from reducing redundancies.

Table 28-20. Final Output for Example 3, After Assigning Characteristic Curve

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXAMPLE 3

NODE DATA Page 1

NODE NO.	ELEV. FT.	OUTPUT GPM	E.G.L. FT.	PR.HEAD FT.	PRESSURE PSI	
11	1000.0	-2600.	1000.0			RESERVOIR
21	800.0	100.	936.6	136.6	59.2	
22	800.0	200.	887.7	87.7	38.0	
31	800.0		887.6	87.6	37.9	
32	780.0	300.	856.0	76.0	32.9	
41	800.0		849.4	49.4	21.4	
42	780.0	1200.	831.9	51.9	22.5	
51	800.0		1144.3	344.3	149.2	
61	980.0	300.	1039.9	59.9	42.0	
71	950.0	500.	996.1	46.1	20.0	

PIPE DATA

PIPE NO.	NODES FROM	NODES TO	DIAM. IN.	LENGTH FT.	COEF	FLOW GPM	VEL. FT/SEC	HEAD LOSS
11	11	21	16.0	10560.0	100.*	2600.	4.1	63.4
21	21	31	12.0	5280.0	100.*	1545.	4.4	49.1
22	22	32	10.0	5280.0	100.*	755.	3.1	31.7
31	31	41	14.0	5280.0	100.*	1348.	3.8	38.1
32	32	42	10.0	5280.0	100.*	652.	2.7	324.1
41	41	51	PUMP HEAD	294.9	FT	800.	POWER	60. HP
51	51	61	8.0	5280.0	100.*	800.	5.1	104.5
61	61	71	8.0	5280.0	100.*	500.	3.2	43.7
121	21	22	10.0	5280.0	100.*	955.	3.9	48.9
131	31	32	6.0	5280.0	100.*	197.	2.2	31.5
141	41	42	10.0	5280.0	100.*	548.	2.2	17.5

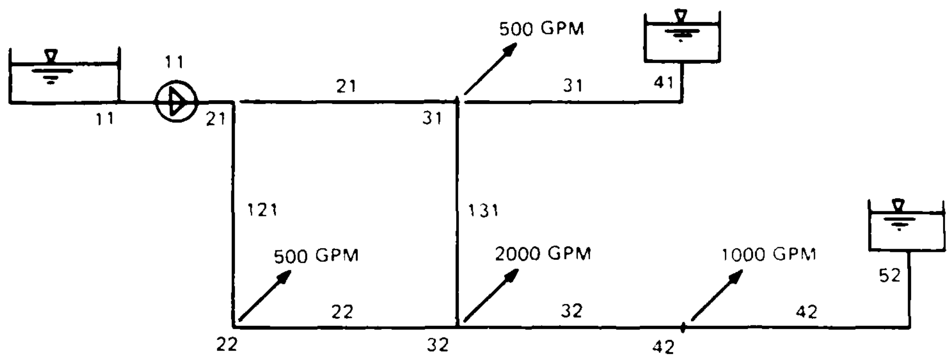

Figure 28-9. System layout, Example 4

a. System Data. The data are entered through the simulation routine. In the program control menu, option 1 (SIMULATION) is selected. In the first simulation routine menu, again option 1 (TO ENTER NEW JOB) is selected. The prompt-by-prompt and line-by-line input is presented below. The input table is shown as Table 28-21.

```
S. KEYWORD IS JOB ENTER (KEYWORD) DATA LIST
? EXAMPLE 4
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? PUMP 11 11 21
POINT 1 ON CHARACTERISTIC CURVE:  ENTER DISCHARGE, HEAD
? 1500 350
POINT 2 ON CHARACTERISTIC CURVE:  ENTER DISCHARGE, HEAD
? E
S. KEYWORD IS PUMP ENTER (KEYWORD) DATA LIST
? 21 21 31 16 10560
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 22 22 32 16 10560
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 31 31 41 16 10560
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 32 32 42 16 10560
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 42 42 52 16 5280
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 121 21 22 16 5280
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? 131 31 32 16 5280
S. KEYWORD IS PIPE ENTER (KEYWORD) DATA LIST
? NODE
FOR NODE 11 ENTER ELEVATION OUTPUT
? 100
FOR NODE 21 ENTER ELEVATION OUTPUT
? 100
```

Table 28-21. Input Data for Example 4

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXAMPLE 4

NODE NO.	ELEV. FT.	OUTPUT GPM		
11	100.0		RESERVOIR	
21	100.0	0.		
22	350.0	500.		
31	350.0	500.		
32	350.0	2000.		
41	385.0		WATER LEVEL:	80.0
42	350.0	1000.		
52	400.0		WATER LEVEL:	80.0

PIPE CONNECTIONS

PIPE NO.	B NODE	E NODE	DIAM. IN.	LENGTH FT.	H-W C	
11	11	21				PUMP
21	21	31	16.0	10560.0	100.*	
22	22	32	16.0	10560.0	100.*	
31	31	41	16.0	10560.0	100.*	
32	32	42	16.0	10560.0	100.*	
42	42	52	16.0	5280.0	100.*	
121	21	22	16.0	5280.0	100.*	
131	31	32	16.0	5280.0	100.*	

PUMP COEFFICIENTS FOR PUMP 11

Q*Q	Q	CONSTANT
-10.4454	-.0010	466.7

```
FOR NODE 22 ENTER ELEVATION OUTPUT
? 350 500
FOR NODE 31 ENTER ELEVATION OUTPUT
? 350 500
FOR NODE 32 ENTER ELEVATION OUTPUT
? 350 2000
FOR NODE 41 ENTER ELEVATION OUTPUT
? 385
FOR NODE 42 ENTER ELEVATION OUTPUT
? 350 1000
FOR NODE 52 ENTER ELEVATION OUTPUT
? 400
S. KEYWORD IS TANK ENTER (KEYWORD) DATA LIST
? 11 0
S. KEYWORD IS TANK ENTER (KEYWORD) DATA LIST
? 41 80
S. KEYWORD IS TANK ENTER (KEYWORD) DATA LIST
? 52 80
S. KEYWORD IS TANK ENTER (KEYWORD) DATA LIST
? END
```

Arbitrarily, all pipes were assigned a diameter of 16 inches. The pump was entered with a head of 350 feet at a discharge of 1,500 gallons per minute, using the default curve. Output of the balanced system is shown as Table 28-22.

b. Cost Data. The same cost data are used as in Example 3 (see Table 28-18).

c. Optimization Parameters. Pipes 21, 31, and 131 each form one group: groups 1, 2, and 4, respectively. Pipes 22 and 121 form group 3, and pipes 32 and 42 form group 5. No price functions are specified, i.e., all pipes will default to function 1. Selection of size ranges is more difficult. It may not be immediately obvious that the main supply is to come through pipes 32 and 42, i.e., group 5. Experimentation in the simulation routine and/or some preliminary runs in the optimization routine can help to clarify what size ranges may be reasonable. Such experimentation shows that groups 1 through 4 can be kept small, while group 5 needs to be large. Two loading patterns are specified: the first one has loads as entered in the simulation routine, and the minimum pressure to be maintained is 40 pounds per square inch. The second pattern has flow rates 50 percent higher than pattern 1, and the minimum pressure must be at least 25 pounds per square inch. Pattern 1 is to be used for 42 percent of the time and pattern 2 for 18 percent of the time. These percentages are specified with the keywords LOAD and PUMP. Pump efficiency is 75 percent. The optimization parameters are listed in Table 28-23. Upon selecting option 0, OPTIMIZATION, in the menu of the optimization routine, the program will respond with the following output:

Table 28-22. First Output for Example 4

PIPF NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXAMPLE 4

NODE DATA Page 1

NODE NO.	ELEV. FT.	OUTPUT GPM	E.G.L. FT.	PR.HEAD FT.	PRESSURE PSI	
11	100.0	-1421.	100.0			RESERVOIR
21	100.0		462.0	362.0	156.8	
22	350.0	500.	457.5	107.5	46.6	
31	350.0	500.	458.8	108.8	47.1	
32	350.0	2000.	455.5	105.5	45.7	
41	385.0	-741.	465.0	80.0	34.7	SUPPLY
42	350.0	1000.	463.3	113.3	49.1	
52	400.0	-1838.	480.0	80.0	34.7	SUPPLY

PIPE DATA

PIPE NO.	NODES FROM	NODES TO	DIAM. IN.	LENGTH FT.	COEF	FLOW GPM	VEL. FT/SEC	HEAD LOSS	
11	11	21	PUMP HEAD	362.0	FT	1421.	POWER	130.	HP
21	21	31	16.0	10560.0	100.*	519.	.8	3.2	
22	22	32	16.0	10560.0	100.*	402.	.6	2.0	
31	41	31	16.0	10560.0	100.*	741.	1.2	6.2	
32	42	32	16.0	10560.0	100.*	838.	1.3	7.8	
42	52	42	16.0	5280.0	100.*	1838.	2.9	16.7	
121	21	22	16.0	5280.0	100.*	902.	1.4	4.5	
131	31	32	16.0	5280.0	100.*	760.	1.2	3.3	

Table 28-23. Optimization Parameters for Example 4

```
OPTIMIZATION PARAMETERS

GROUP ASSIGNMENTS

PIPES IN GROUP    1 :
 21
PIPES IN GROUP    2 :
 31
PIPES IN GROUP    3 :
 22 121
PIPES IN GROUP    4 :
 131
PIPES IN GROUP    5 :
 32  42

PRICE FUNCTION ASSIGNMENTS

PIPES IN PRICE FCT.    1 :
 21  22  31  32  42 121 131

SIZE ASSIGNMENTS

GROUP #     SIZES ASSIGNED:
    1     6.0   8.0  10.0
    2     6.0   8.0  10.0
    3     6.0   8.0  10.0
    4     6.0   8.0  10.0
    5    18.0  20.0  24.0

LOADING PATTERNS

             LOADS IN GPM  AND  MIN. PRESSURE IN PSI
PATTERN #         1     *       2      *
NODE # *    GPM     PSI*   GPM     PSI*
  21   *      0.  40.0*      0.  25.0*
  22   *    500.  40.0*    750.  25.0*
  31   *    500.  40.0*    750.  25.0*
  32   *   2000.  40.0*   3000.  25.0*
  42   *   1000.  40.0*   1500.  25.0*

              PUMP EFFICIENCY %  AND  % TIME RUNNING
PATTERN #                    1 *         2  *
PUMP #  EFFIC.                 *            *
  11    * 75.0     *      42.0 *       18.0 *

COEF. FOR CLEANING 120.
PRESSURE TOLERANCE -3. PSI
COST TOLERANCE     +3. %
```

```
IN GROUP 3:  SIZE 6.0 ELIMINATED

     GROUP 1,  # OF SIZES:  3
     GROUP 2,  # OF SIZES:  3
     GROUP 3,  # OF SIZES:  2
     GROUP 4,  # OF SIZES:  3
     GROUP 5,  # OF SIZES:  3

          162 COMBINATIONS WILL BE TESTED.

JOB IS 10. % COMPLETE
 BEST SOLUTION:
     GROUP      1       2       3      4      5
     DIAM.    8.0     8.0     8.0   10.0   20.0
     AT COST OF       2396614.
     MIN. PRESSURE            4.7

JOB IS 20. % COMPLETE
 BEST SOLUTION:
     GROUP      1       2       3      4      5
     DIAM.    8.0     8.0     8.0   10.0   20.0
     AT COST OF       2396614.
     MIN. PRESSURE            4.7

JOB IS 30. % COMPLETE.
 BEST SOLUTION:
     GROUP      1       2       3      4      5
     DIAM.    8.0     8.0     8.0   10.0   20.0
     AT COST OF       2396614.
     MIN. PRESSURE            4.7

Job IS 40. % COMPLETE
 BEST SOLUTION:
     GROUP      1       2       3      4      5
     DIAM.    8.0     8.0     8.0   10.0   20.0
     AT COST OF       2396614.
     MIN. PRESSURE            4.7

JOB IS 50. % COMPLETE
 BEST SOLUTION:
     GROUP      1       2       3      4      5
     DIAM.    6.0     6.0     8.0   10.0   20.0
     AT COST OF       2281925.
     MIN. PRESSURE            0.1

JOB IS 60. % COMPLETE
 BEST SOLUTION:
     GROUP      1       2       3      4      5
     DIAM.    6.0     8.0     8.0    8.0   20.0
     AT COST OF       2276147.
     MIN. PRESSURE            2.9
```

```
JOB IS 70. % COMPLETE
 BEST SOLUTION:
     GROUP       1       2       3      4      5
     DIAM.     6.0     8.0     8.0    6.0   20.0
     AT COST OF        2252146.
     MIN. PRESSURE              0.7

JOB IS 80. % COMPLETE
 BEST SOLUTION:
     GROUP       1       2       3      4      5
     DIAM.     6.0     8.0     8.0    6.0    20.0
     AT COST OF        2252146.
     MIN. PRESSURE              0.7

JOB IS 90. % COMPLETE
 BEST SOLUTION:
     GROUP       1       2       3      4      5
     DIAM.     6.0     8.0     8.0    6.0    20.0
     AT COST OF        2252146.
     MIN. PRESSURE              0.7

OPTIMUM SOLUTION:

     GROUP       1       2       3      4      5
     DIAM.     6.0     8.0     8.0    6.0   20.0
     AT COST OF        2252146.
     MIN. PRESSURE              0.7
     IN PATTERN                 2

ALTERNATIVE SOLUTIONS:

DIAM.     8.0    6.0    8.0    8.0   20.0
MIN.PR.    3.2 IN PATTERN      2 COST    2302969.

DIAM.     6.0    8.0    8.0    8.0    20.0
MIN.PR.    2.9 IN PATTERN      2 COST    2276147.
```

Since optimization was carried out with a fixed characteristic curve, the user can access the simulation routine directly for a final rebalancing, before printing the output corresponding to the worst loading pattern. The output is reproduced in Table 28-24.

28-33. Example 5. The purpose of this example is to show how pipe size combinations are enumerated while optimizing a system. By choosing the OE option from the optimization menu, each combination of pipe sizes tested will be displayed. The same system layout that was used in Example 4, shown in Figure 28-9, will be used for this example. Pipe sizes will correspond to the optimal sizes of Example 4, shown in Table 28-24. Cost data from Example 4 will also be used. For the optimization parameters, pipes 21 and 121 will form group 1, pipes 22 and 131 will form group 2, and pipe 31 will form group 3. Sizes of 2, 4, 6, and 8 inches will be used for groups 1 and 3, and

Table 28-24. Final Output for Example 4

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXAMPLE 4

NODE DATA Page 1

NODE NO.	ELEV. FT.	OUTPUT GPM	E.G.L. FT.	PR.HEAD FT.	PRESSURE PSI	
11	100.0	-1012.	100.0			RESERVOIR
21	100.0		513.6	413.6	179.2	
22	350.0	750.	419.7	69.7	30.2	
31	350.0	750.	410.0	60.0	26.0	
32	350.0	3000.	419.7	69.7	30.2	
41	385.0	-389.	465.0	80.0	34.7	SUPPLY
42	350.0	1500.	449.3	99.3	43.0	
52	400.0	-4599.	480.0	80.0	34.7	SUPPLY

PIPE DATA

PIPE NO.	NODES FROM	NODES TO	DIAM. IN.	LENGTH FT.	COEF	FLOW GPM	VEL. FT/SEC	HEAD LOSS	
11	11	21	PUMP HEAD	413.6	FT	1012.	POWER	106.	HP
21	21	31	6.0	10560.0	100.*	257.	2.9	103.6	
22	22	32	8.0	10560.0	100.*	5.	.0	.0	
31	41	31	8.0	10560.0	100.*	389.	2.5	55.2	
32	42	32	20.0	10560.0	100.*	3099.	3.2	29.6	
42	52	42	20.0	5280.0	100.*	4599.	4.7	30.7	
121	21	22	8.0	5280.0	100.*	755.	4.8	93.9	
131	31	32	6.0	5280.0	100.*	104.	1.2	9.7	

sizes of 4, 6, and 8 inches will be used for group 2. A minimum pressure of 25 pounds per square inch is to be maintained, and pump 11 is to operate 50 percent of the time with a wire-to-water efficiency of 75 percent. Table 28-25 shows the optimization parameters. Option OE is selected from the optimization menu, and the program responds with this output:

```
IN GROUP 1:  SIZE 2.0 ELIMINATED
IN GROUP 1:  SIZE 4.0 ELIMINATED
IN GROUP 1:  SIZE 6.0 ELIMINATED

12 COMBINATIONS WILL BE TESTED.
```

COMB. #	COST	MIN. PRESS.	REASON FAILED	GROUP SIZES		
1	1049959.	- - - -	COST	8.0	8.0	8.0
2	983431.	- - - -	COST	8.0	6.0	8.0
3	915500.	0.9		8.0	4.0	8.0
4	1005607.	- - - -	COST	8.0	8.0	6.0
5	941656.	1.5		8.0	6.0	6.0
6	878422.	-3.1	PRESSURE	8.0	4.0	6.0
7	960199.	- - - -	COST	8.0	8.0	4.0
8	901281.	-6.0	PRESSURE	8.0	6.0	4.0
9	590832.	- - - -	SIZE	8.0	4.0	4.0
10	917057.	-2.3		8.0	8.0	2.0
11	611318.	- - - -	SIZE	8.0	6.0	2.0
12	543206.	- - - -	SIZE	8.0	4.0	2.0

```
 OPTIMUM SOLUTION:
GROUP          1        2       3
DIAM.       8.0      4.0     8.0
AT COST OF              915500.
MIN. PRESSURE               0.9
IN PATTERN                  1

 ALTERNATIVE SOLUTIONS:

DIAM.     8.0     6.0     6.0
MIN.PR.    1.5 IN PATTERN 1 COST  941656.
```

The costs of the combinations shown above which failed the cost test are the sum of the piping cost of the group sizes for the combination and the lowest possible pumping cost. The lowest possible pumping cost is based on the maximum pipe diameters in each group. The minimum pressure displayed is the actual pressure minus the required pressure. For combinations that have only dashes displayed for the minimum pressure, the minimum pressure was not calculated either because the combination was too expensive or because all sizes in the combination were less than or equal to sizes of a combination that was previously tested and failed to meet the pressure requirement. Note that only one alternative solution was listed because the other possible combination, with a minimum pressure of -2.3 pounds per square inch, gave less pressure than the optimum solution at a higher cost and is not Pareto Optimal.

Table 28-25. Optimization Parameters for Example 5

```
OPTIMIZATION PARAMETERS

GROUP ASSIGNMENTS

PIPES IN GROUP  1:
 21 121

PIPES IN GROUP  2:
 22 131

PIPES IN GROUP  3:
 31

PRICE FUNCTION ASSIGNMENTS

PIPES IN PRICE FCT.  1:
 21 22 31 121 131

SIZE ASSIGNMENTS

GROUP#   SIZES ASSIGNED:
     1     2.0  4.0  6.0  8.0
     2     4.0  6.0  8.0
     3     2.0  4.0  6.0  8.0

LOADING PATTERNS

          LOADS IN GPM AND MIN. PRESSURE IN PSI
PATTERN #      1        *
NODE # *     GPM    PSI *
  21   *       0.  25.0*
  22   *     750.  25.0*
  31   *     750.  25.0*
  32   *    3000.  25.0*
  42   *    1500.  25.0*

          PUMP EFFICIENCY % AND % TIME RUNNING
PATTERN #               1   *
PUMP #  EFFIC.              *
  11   *  75.0    *    50.0 *

COEF. FOR CLEANING 120.0

PRESSURE TOLERANCE  -3.0 PSI
COST TOLERANCE      +3.0 %
```

Section 6. Program Control for Extended Period (Time) Simulation Routine

28-34. Introduction. The extended period simulation routine (also referred to as "Time Simulation") is accessed from the program control menu (see paragraph 28-8) by selecting option 4. Prior to entering the extended period simulation, the system must already be entered using the steady-state simulation routine and balanced. (See paragraphs 28-7 through 28-18 for details on the steady-state simulation routine.)

28-35. Option Menu. Within the extended period simulation routine, program execution is controlled by seven options. The user may select from starting the extended period simulation, entering or modifying the extended period simulation data, printing the input data, storing the data on a user-selected file, retrieving the data from a previously created file, returning to the main program control menu, and terminating the program. The option menu, as it appears at the terminal, is displayed below.

```
 TIME SIMULATION MENU

SELECT PROGRAM OPTION:

  BEGIN SIMULATION    : ENTER 0, PRESS RETURN
  MODIFY,ENTER DATA   :       1
  PRINT TIME DATA     :       2
  STORE TIME DATA     :       3
  RETRIEVE TIME DATA  :       4
  PROGRAM CONTROL     :       8
  TERMINATE           :       9
```

After the completion of options 0 through 4, program control returns to this menu. Option 8 returns to the program control menu, and option 9 terminates the program.

28-36. Description of Options. A general description of each of the menu options follows.

a. BEGIN SIMULATION. This option starts the extended period simulation. For additional details, see paragraph 28-41. Before selecting this option, all data must have been previously entered as described in paragraph 28-38.

b. MODIFY, ENTER DATA. This option allows the user to enter the time simulation data or change any of the time simulation parameters. (See paragraph 28-38.)

c. PRINT TIME DATA. This option prints the data that were entered or modified in the input routine. (See paragraph 28-39.)

d. STORE TIME DATA. This option stores the time data entered under b. on a user-selected file as an internal data file. Data are not automatically stored by the program. (See paragraph 28-40.)

e. RETRIEVE TIME DATA. This option allows the user to retrieve data that were stored under d. above.

f. PROGRAM CONTROL. This option returns control to the program control menu.

g. TERMINATE. This option terminates the run.

28-37. Definition of Terms. The following terms are used in connection with the time simulation routine.

a. Base Water Use. The water use that is assigned to nodes in the steady-state simulation routine multiplied by the constant entered with the keyword RATIO in the time simulation routine.

b. Duration. The time in hours that is simulated during an extended period simulation run.

c. Extended Period Simulation. Simulation of pressures, flows, tank water levels, and varying water use patterns over time.

d. Loading Factor. Factor by which the output at a node is multiplied to describe the water use for a given time step. For example, if the water use is 1,000 gallons per minute and the loading factor for a time step is 1.2, the water use during that time step is 1,200 gallons per minute.

e. Spatial Distribution. Defines which nodes are assigned to a particular water use pattern. For instance, in a system, some water use nodes may be governed by a residential water use pattern and others by a commercial water use pattern.

f. Step Size. The period of time in hours equal to the duration divided by the number of time steps. For example, if the duration of the extended period simulation is 24 hours and number of time steps is 8, the time step size is equal to 3 hours. This is the user time step. The program also calculates and uses internal time steps based on changes in flows at tanks and when pumps (or pipes) turn on and off.

g. Time Step. The number assigned to the period of time for which a particular loading factor is applied to a water use at a node. To relate time step, step size, and time, use these equations:

$$t = (N - 1)\ \Delta t$$

or

$$N = (t/\Delta t) + 1$$

where

N = number of the time step (e.g., $N = 3$ indicates the third time step)

Δt = step size, hours/step (duration divided by the total number of time steps)

t = time at which time step N begins, hours.

For example, if the step size is 0.5 hour per step, the time at the beginning of the sixth time step is

$$t = (6 - 1)\ 0.5 = 2.5 \text{ hours}$$

and the time step assigned to time 6.5 hours to 7 hours is

$$N = (6.5/0.5) + 1 = 14^{th} \text{ step}$$

h. Water Use Pattern. A series of loading factors over time. Each time step is assigned a loading factor.

28-38. Data Input. Input of the time simulation data is similar to the input of the simulation and optimization data. A set of keywords, summarized in Table 28-26, enables the user to enter the time simulation data. To enter time simulation data, select the "MODIFY,ENTER" option, and data will be requested with the following prompt

T. KEYWORD IS (xxxx) ENTER (KEYWORD) DATA LIST

The T. indicates that the prompt refers to the extended period (time) simulation data, and xxxx represents the current default keyword (e.g., DURATION). All keywords can be abbreviated with the first four letters. Numeric values following the keyword must be separated by a blank or a comma, and there must be a blank or comma between a keyword and numeric value. If data are entered without a keyword, the keyword displayed in the prompt will be used. Each of the keywords and their formats are described below.

a. DURATION. This keyword is used to enter the number of hours for which the simulation is to take place. The format for the keyword is given below.

```
            Hours of Simulation
DURATION          48
```

In this case, the program will simulate 48 hours of operation. If duration is not specified, the program will simulate 24 hours of operation.

b. STEPS. This keyword is used to specify the number of time steps for the extended period simulation. The format is given below.

```
           Number of Steps
STEPS             8
```

Table 28-26. Keywords for Extended Period Simulation (T. Prompt)

BEGIN	XX Link#	ON			
or					
BEGIN	XX Link#	OFF			
DETAIL	ON				
or					
DETAIL	OFF				
DURATION	XX.X Hours of Simulation				
EXCLUDE	XX Link#	XX.X Beg. Hour	XX.X End Hour		
END					
INCLUDE	XX XX XX List of Link #				
FIRE	XX Node #	XX.X Beg. Time Step	XX.X Duration Time Step	XX.X Flow,gpm	
or					
FIRE	XX Node #				
PLINK	XX XX XX . . . List of Link #				
or					
PLINK	XX XX XX . . . DELETE List of Link #				
PNODE	XX XX XX . . . List of Node #				
or					
PNODE	XX XX XX . . . DELETE List of Node #				
PUMP	XX Link#	LEFT	XX Tank #	XX On Level, ft	XX Off Level, ft
or					
PUMP	XX Link #	LEPSI	XX Node #	XX On Press., psi	XX Off Press., psi.
or					
PUMP	XX Link #	TIME	XX.X Beg. Hour	XX.X End Hour	
or					
PUMP	XX Link #				
RATIO	XX.X Ratio				

(Continued)

Table 28-26. (Concluded)

SPATIAL	XX	NODES	XX XX XX ...		
	Pattern #		List of Nodes		
or					
SPATIAL	XX	RANGE	XX	XX	
	Pattern #		First Node	Last Node	
STEPS	XX				
	Number of Steps				
TANK	XX	XX	XX	XX	(XX)
	Node #	Max HT,ft	Min HT,ft	Area,sqft	Init. HT,ft
or					
TANK	XX				
	Node #				
USAGE	XX	XX.X1	XX.X2		
	Pattern #	Beg Time Step	End Time Step		

The time specified with keyword DURATION will be divided into eight equal time periods. Up to 56 time steps for a given duration may be specified. The length of an individual time step is the duration divided by the number of steps. If the user does not specify the number of time steps, the default value is 24 steps.

c. TANK. This keyword is used to assign extended period simulation data to a tank. The format for this keyword is given below.

	Node #	Max HT (ft)	Min HT (ft)	Area (sqft)	Init Water level (ft)
TANK	30	110	90	1000	105

The elevations shown are water heights in the tank measured above the node elevation specified in the steady-state simulation. The initial water level is optional. If not entered, the water level specified in the steady-state simulation is assigned to the initial water elevation. When entering the maximum and minimum water heights, the value of the maximum water height must always exceed the value of the minimum water height. If during the extended period simulation the water level in the tank reaches either the maximum or minimum water height, the tank is disconnected from the remainder of the system. Actually, the program will disconnect the link(s), connected to the tank, from the system. To prevent the network from being discontinuous at the tank, it is advised that no in-line tanks be used. The illustration below shows the correct and incorrect way to connect tanks to the system.

CORRECT INCORRECT

The area is an average horizontal cross-sectional area of the tank. If the water level in the tank is to remain constant during the entire extended period simulation, the user should specify an area of 0 for the tank. The program will use an area of 1E10 for the tank so the water level will not fluctuate. Any node entered with keyword tank must have been previously declared as a tank in the steady-state simulation routine. Up to 20 tanks may be assigned data for the extended period simulation. Tanks can be excluded from the extended period simulation with the following format:

```
        NODE #
TANK      21
```

When deleting a tank from the extended period simulation, it must also be deleted from the steady-state simulation, by assigning the node an output. If tanks in the steady-state simulation are not entered with keyword TANK, they are treated as constant head nodes (e.g., no fluctuation in water level).

d. <u>USAGE</u>. This keyword is used to assign water use loading factors over a range of time steps. These values are entered on two separate lines. The format is given below.

```
                         Beginning       Ending
            Pattern #    Time step       Time step
USAGE           2            2               7
```

Next, the program prompts the user to enter values (six for this case) showing the relative water loading factors for each time step as follows.

```
ENTER 6 VALUES
? 1  1  1.2  1.3  1.0  .8
```

After the user enters the six values, the program returns to the input prompt. A loading factor may also be assigned to a single time step and pattern with this format.

```
      Pattern #  Time step
USAGE     1          2
```

The program responds with

```
ENTER 1 VALUE
?
```

After entering the value, the program returns to the input prompt. Fifteen relative water loading factors may be entered per line. If the time simulation contains more than 15 steps, loading factors must be entered in more than one step. For example, if the time simulation is divided into [illegible] steps, [illegible] the loading factors in two steps.

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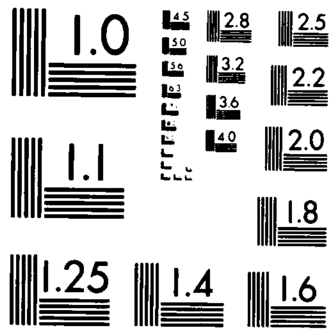

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	Pattern #	Beginning Time Step	Ending Time Step
USAGE	1	1	15

The program prompts for 15 values. After entering the 15 values, type

	Pattern #	Beginning Time Step	Ending Time Step
USAGE	1	16	24

The program prompts for the remaining nine values. Up to five usage patterns may be specified for an extended period simulation.

e. SPATIAL. This keyword is used to assign water use patterns to a range of nodes or to individual nodes. To assign a water use pattern to a range of nodes, the format is:

	Pattern #		First node	Last node
SPATIAL	1	RANGE	11	33

All water use nodes with numbers ranging from 11 to 33, excluding tanks, will follow in water use pattern 1. The beginning node for the range of nodes must always be less than the ending node. To assign a water use pattern to individual nodes, the format is:

	Pattern #		Node numbers
SPATIAL	2	NODES	3 10 26 27

Nodes 3, 10, 26, and 27 will follow water use pattern 2. Every water use node, except constant head nodes, must be assigned to a water use pattern. Water use nodes not assigned to a use pattern will follow use pattern 1. Keyword USAGE defines water use patterns. For instance, some nodes may be assigned to a residential water use and others a commercial water use pattern.

f. RATIO. This keyword can be used to multiply the water use rates in the steady-state simulation by a correction factor. The format is given below.

RATIO 1.5

All water use rates at nodes in the steady-state simulation will be multiplied by 1.5 before being multiplied by the loading factor (e.g., to correspond to peak-day use). RATIO cannot be applied to an individual node.

g. FIRE. This keyword is used to instruct the program to simulate a fire flow at a node for a specific time period. The format is given below.

	NODE #	Beginning Time Step	Ending Time Step	Flow (gpm)
FIRE	9	2	3	1000

Up to five nodes with fire flows can be specified. Note that the beginning and duration of the fire are given in time steps, not hours. Also, the starting time step cannot exceed the total number of time steps, and the time at which the fire ends (starting time step plus duration) should not exceed total number of time steps. The fire flow will override any previous water use assigned to the node with the keyword USAGE. A fire flow assignment at a node may be deleted with the following format:

	NODE #
FIRE	9

All fire data at node 9 are deleted, and the previous water use at the node, if any, is reassigned to the node. Constant head nodes cannot be assigned a fire flow.

h. PUMP. This keyword is used to tell the program to simulate manual or automatic control of pumps in a system during an extended period simulation. Pumps can be controlled by tank water levels, pressure at a node, or time. The following format is used to control pumps by tank water levels.

	LINK #		TANK #	On Level Feet	Off Level Feet
PUMP	5	LEFT	3	100	125

Pump 5 will start pumping when the water level in tank 3 drops to 100 feet (measured above the node elevation specified in the steady-state simulation) and stop pumping when the tank water elevation reaches 125 feet. The tank water levels specified when using keyword LEFT (level in feet) should fall within the maximum and minimum tank water levels specified with the keyword TANK in the extended period simulation (paragraph 28-37c). Be careful not to connect the suction side a pump to a tank that may drain during the simulation. Also, the water level at which the pump begins pumping should be less than the water level at which the pump turns off. If the values are too close, pumps will cycle on and off rapidly, and program run times will be large. To control pumps by pressure at a node, the format is

	LINK #		NODE #	On Pressure psi	Off Pressure psi
PUMP	5	LEPSI	7	30	40

Pump 5 will start pumping when the hydraulic grade line at node 7 reaches 30 pounds per square inch * (2.308) plus the elevation of the node specified in the steady-state simulation and will stop pumping when the hydraulic grade line reaches 40 pounds per square inch * (2.308) plus the elevation of the node. The on pressure specified with keyword LEPSI (level in pounds per square inch) should be less than the off pressure. If controlling pumps by pressure at a tank, use water level control. To control pumps by time, the format is

	LINK #		Beginning Hour	Ending Hour
PUMP	5	TIME	2	5

This entry will start pump 5 running at the beginning of hour 2. After 3 hours, pump 5 will stop pumping. To turn pumps on and off several times during a simulation, the format is

	LINK #		Beg. Hour	End. Hour	Beg. Hour	End. Hour	Beg. Hour	End. Hour
PUMP	5	TIME	2.3	4.5	6.2	9	12.83	15

Pump 5 will start pumping at time 2.3 hours, stop at time 4.5 hours, start at time 6.1 hours, stop at time 9 hours, start at time 12.83 hours, and stop at time 15 hours. Up to seven on and off times may be specified. Note that the start of pumping and end of pumping are given in hours, not time steps. Up to 20 pumps may have controls specified for an extended period simulation. Combining tank water level (or node pressure) and time control is also possible. Tank water level will override time control. All pump controls can be deleted with this format.

```
        LINK #
PUMP      5
```

i. BEGIN. This keyword is used to initially turn on or off those pumps entered with keyword PUMP (paragraph 28-38h). To initially turn pumps on, the format is:

```
         LINK #
BEGIN      5       ON
```

To initially turn pumps off, the format is:

```
         LINK #
BEGIN      5       OFF
```

The program will override this when the initial pressure at a node controlling the pump is below the on-pressure limit or, for a pump controlled by time, when it is initially turned on at hour 0 (zero). If this keyword is not used, pumps in the extended period simulation will initially be turned on.

j. PLINK. This keyword is used to assign links for which flows will be printed at the end of each time step. The format is given below.

```
           List of Links
PLINK         3  2  6
```

Flows in gallons per minute through links 3, 2, and 6 will be displayed at the end of each time step. Pumps, check valves, and PRVs may be included in the list. Flows through PRVs will not be displayed; instead, their status (active, open, or closed) will be displayed. To delete links from the list, the format is

```
           List of Links
PLINK         3  4  7      DELETE
```

Flows through links 3, 4, and 7 will not be displayed at the end of each time. The sum of nodes and links displayed cannot exceed 10.

k. PNODE. This keyword is used to assign nodes or tanks for which pressures or tank water levels will be displayed at the end of each time step or when a pump turns on or off. The format is given below.

	List of Nodes
PNODE	5 7 8 12

For all nodes in the list which are tanks, the water levels in the tanks will be displayed at the end of each time step. Pressures at other nodes will be shown. To delete nodes from the list, the format is:

	List of Nodes		
PNODE	5	12	DELETE

Pressures (or tank water levels) will not be displayed for nodes 5 and 12. If no nodes are specified with keyword PNODE and no links with keyword PLINK, tank water levels at the end of each time step will be shown. The sum of nodes and links displayed cannot exceed 10.

l. DETAIL. This keyword provides printing of flows through links and heads of nodes specified with keywords PLINK and PNODE at each internal time step. In addition to the time steps identified by the user where loading factors change, the program calculates internal time steps based on changes in inflows and outflows to tanks and when pumps or PRVs will change status. To print flows and heads at each internal time step, the format is "DETAIL ON." To turn the detailed printing off, the format is "DETAIL OFF." The default is off where flows and heads are printed only at the end of each time step defined by the user.

m. EXCLUDE. This keyword is used to remove links from the network for portions of an extended period simulation (e.g., to simulate a pipe break). The format is:

	Link #	Start Hour	End Hour
EXCLUDE	11	3.50	9.50

This entry will close pipe link 11 at time 3.50 hours and reopen the pipe at time 9.50 hours. All pipes are considered open at the beginning of the simulation unless the beginning hour of exclusion is 0 hours. To close a pipe and reopen the pipe several times during an extended period simulation, the format is:

	Link #	Start Hour	End Hour	Start Hour	End Hour	Start Hour	End Hour
EXCLUDE	13	0	3	6	9	12	15

Pipe 13 will close at time 0 hours, open at time 3 hours, close at time 6 hours, open at time 9 hours, close at time 12 hours, and open at time 15 hours. Up to seven pairs of close and open times may be specified. Note that times are in hours, not time steps. Up to 15 pipes may be excluded from the system; however, PRVs and check valves may not be excluded. Pumps may not be excluded with this keyword, but can be turned off with keyword PUMP (paragraph 28-38h).

n. INCLUDE. This keyword is used to reinsert links that have been previously removed from the system with the EXCLUDE keyword. The format is given below.

```
          List of links
INCLUDE    15  22  33
```

Pipe links 15, 22, and 33 will now be considered for the extended period simulation. If the user attempts to include a pipe that was not previously excluded, a warning message will be printed.

o. END. This keyword terminates the data entry for the extended period simulation. The program returns to the time simulation menu.

28-39. Printing of Time Data. All time simulation data entered under paragraph 28-38 are printed when the user selects "PRINT TIME DATA" from the time simulation menu. Displayed are the time simulation duration, the time step size, the number of time steps, the ratio of outputs from the steady-state simulation, water use patterns for each time step and nodes assigned to each pattern, tank data, fire event data, links that are out of service, node usage patterns, and nodes and links that will have output displayed at the end of each time step. After printing, control returns to the time simulation menu.

28-40. Storage and Retrieval of Time Simulation Data. The time simulation parameters entered (paragraph 28-38) and printed (paragraph 28-39) can be stored in a user-selected file name. When selecting "STORE TIME DATA" (option 3) in the menu, the program responds with the prompt "ENTER FILE NAME." The user enters any file name that conforms with the file name requirements of the computer system. Data stored under this option can be retrieved by selecting "RETRIEVE TIME DATA" (option 4) in the menu.

28-41. Time Simulation. To begin the extended period simulation, the user selects option 0 in the time simulation menu. The program calculates the level of the energy grade line and pressure at each node, the flows and head losses in each pipe, the flow and head for each pump, and the mode of operation for each pump, PRV, and check valve for unsteady-state conditions. Fluctuations in tank levels and varying water use patterns over time are considered. At the end of each time step, flows through those links that were specified with keyword PLINK are printed. At the end of each time step, the program also prints pressures at nodes (or tank water levels at nodes which are tanks) for those nodes specified with keyword PNODE. At the end of a time step and at the beginning of the next time step, the program records the water levels for each tank in the system and minimum pressures and nodes where the

minimum pressure occurred. These values are displayed at the end of the simulation. Program control returns to the menu of the extended period (time) simulation routine. It is then possible to modify time parameters or return to the main program menu, and then to the steady-state simulation to update and expand the present system.

28-42. Example 6.

a. Network Description. The network for this example is shown is Figure 28-10. The purpose of this example is to illustrate entering of the extended period (time) simulation parameters. Pump 9 shown in the network will be controlled by the water level in tank 2. A fire flow will occur at node 22 for 1 hour during the simulation. Water uses at nodes will vary over time, and water levels in tanks 2 and 25 will fluctuate over time.

b. System Data Input. Prior to entering any time data, system data must be entered in the steady-state simulation routine. Data entry, starting from the main program menu, is shown here.

```
 PROGRAM CONTROL :

          SIMULATION        : ENTER  1  PRESS RETURN
          OPTIMIZATION      :        2
          COST DATA         :        3
          TIME SIMULATION   :        4
          TERMINATE PROGRAM :        9

1

 SIMULATION ROUTINE

 SELECT PROGRAM OPTION      :

          TO ENTER NEW JOB : ENTER  1  PRESS RETURN
          TO RETRIEVE DATA :        2

1

S. KEYWORD IS JOB    ENTER (KEYWORD) DATA LIST
EXAMPLE 6
S. KEYWORD IS PIPE   ENTER (KEYWORD) DATA LIST
PUMP 9 9 10
POINT  1 ON CHARACTERISTIC CURVE: ENTER DISCHARGE,   HEAD
1000 300
POINT  2 ON CHARACTERISTIC CURVE: ENTER DISCHARGE,   HEAD
1500 250
POINT  3 ON CHARACTERISTIC CURVE: ENTER DISCHARGE,   HEAD
2000 198
```

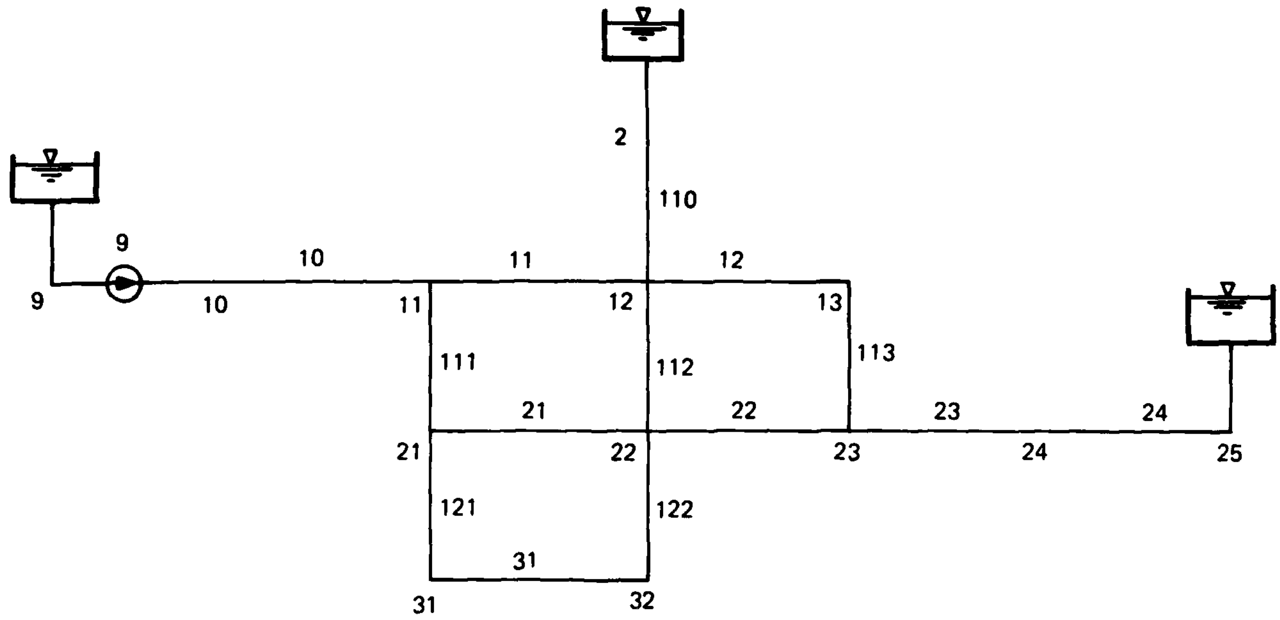

Figure 28-10. System layout, Example 6

```
PUMP COEFFICIENTS FOR PUMP   9.  Q in CFS
       Q*Q          Q  CONSTANT
   -0.8058   -40.3948     394.0
S. KEYWORD IS PUMP   ENTER (KEYWORD) DATA LIST
PIPE 10 10 11 18 10530
S. KEYWORD IS PIPE   ENTER (KEYWORD) DATA LIST
11 11 12 14 5280
S. KEYWORD IS PIPE   ENTER (KEYWORD) DATA LIST
12 12 13 10 5280
S. KEYWORD IS PIPE   ENTER (KEYWORD) DATA LIST
21 21 22 10 5280
S. KEYWORD IS PIPE   ENTER (KEYWORD) DATA LIST
22 22 23 12 5280
S. KEYWORD IS PIPE   ENTER (KEYWORD) DATA LIST
23 23 24 10 8400
S. KEYWORD IS PIPE   ENTER (KEYWORD) DATA LIST
24 24 25 18 200
S. KEYWORD IS PIPE   ENTER (KEYWORD) DATA LIST
31 31 32 6 5280
S. KEYWORD IS PIPE   ENTER (KEYWORD) DATA LIST
110 2 12 18 200
S. KEYWORD IS PIPE   ENTER (KEYWORD) DATA LIST
111 11 21 10 5280
S. KEYWORD IS PIPE   ENTER (KEYWORD) DATA LIST
112 12 22 12 5280
S. KEYWORD IS PIPE   ENTER (KEYWORD) DATA LIST
113 13 23 8 5280
S. KEYWORD IS PIPE   ENTER (KEYWORD) DATA LIST
121 21 31 8 5280
```

```
S. KEYWORD IS PIPE   ENTER (KEYWORD) DATA LIST
122 22 32 6 5280
S. KEYWORD IS PIPE   ENTER (KEYWORD) DATA LIST
NODE
FOR NODE    2  ENTER   ELEVATION, OUTPUT
850
FOR NODE    9  ENTER   ELEVATION, OUTPUT
800
FOR NODE   10  ENTER   ELEVATION, OUTPUT
710
FOR NODE   11  ENTER   ELEVATION, OUTPUT
710 150
FOR NODE   12  ENTER   ELEVATION, OUTPUT
700 150
FOR NODE   13  ENTER   ELEVATION, OUTPUT
695 100
FOR NODE   21  ENTER   ELEVATION, OUTPUT
700 150
FOR NODE   22  ENTER   ELEVATION, OUTPUT
695 200
FOR NODE   23  ENTER   ELEVATION, OUTPUT
690 150
FOR NODE   24  ENTER   ELEVATION, OUTPUT
670 400
FOR NODE   25  ENTER   ELEVATION, OUTPUT
850
FOR NODE   31  ENTER   ELEVATION, OUTPUT
700 100
FOR NODE   32  ENTER   ELEVATION, OUTPUT
710 100
S. KEYWORD IS TANK   ENTER (KEYWORD) DATA LIST
2 120
S. KEYWORD IS TANK   ENTER (KEYWORD) DATA LIST
9 0
S. KEYWORD IS TANK   ENTER (KEYWORD) DATA LIST
25 110
S. KEYWORD IS TANK   ENTER (KEYWORD) DATA LIST
END
```

After the simulation menu appears, select option 2, "PRINT INPUT." Table 28-27 displays the entered data. Now balance the system by selecting option 0 (zero) from the menu. Table 28-28 shows the output from the balancing. When the simulation menu reappears, select option 8, "PROGRAM CONTROL," and then option 4, "TIME SIMULATION," from the program control menu. Data entry of the time simulation parameters beginning from the time simulation menu is shown here.

```
TIME SIMULATION MENU

SELECT PROGRAM OPTION:
```

Table 28-27. Input for Example 6

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXAMPLE 6

NODE NO.	ELEV. FT.	DOM. LOAD GPM	
2	850.0		WATER LEVEL: 120.0
9	800.0		RESERVOIR
10	710.0	0.	
11	710.0	150.	
12	700.0	150.	
13	695.0	100.	
21	700.0	150.	
22	695.0	200.	
23	690.0	150.	
24	670.0	400.	
25	850.0		WATER LEVEL: 110.0
31	700.0	100.	
32	710.0	100.	

PIPE CONNECTIONS

PIPE NO.	B NODE	E NODE	DIAM. IN.	LENGTH FT.	H-W C	
9	9	10				PUMP
10	10	11	18.0	10530.0	100.*	
11	11	12	14.0	5280.0	100.*	
12	12	13	10.0	5280.0	100.*	
21	21	22	10.0	5280.0	100.*	
22	22	23	12.0	5280.0	100.*	
23	23	24	10.0	8400.0	100.*	
24	24	25	18.0	200.0	100.*	
31	31	32	6.0	5280.0	100.*	
110	2	12	18.0	200.0	100.*	
111	11	21	10.0	5280.0	100.*	
112	12	22	12.0	5280.0	100.*	
113	13	23	8.0	5280.0	100.*	
121	21	31	8.0	5280.0	100.*	
122	22	32	6.0	5280.0	100.*	

PUMP COEFFICIENTS FOR PUMP 9

Q*Q	Q	CONSTANT
-0.8058	-40.3948	394.0

Table 28-28. Output for Example 6

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXAMPLE 6

NODE DATA Page 1

NODE NO.	ELEV. FT.	OUTPUT GPM	E.G.L. FT.	PR.HEAD FT.	PRESSURE PSI	
2	850.0	596.	970.0	120.0	52.0	SUPPLY
9	800.0	-1922.	800.0			RESERVOIR
10	710.0		1006.2	296.2	128.4	
11	710.0	150.	985.9	275.9	119.5	
12	700.0	150.	970.0	270.0	117.0	
13	695.0	100.	967.4	272.4	118.0	
21	700.0	150.	970.6	270.6	117.2	
22	695.0	200.	967.5	272.5	118.1	
23	690.0	150.	965.4	275.4	119.3	
24	670.0	400.	960.0	290.0	125.6	
25	850.0	-165.	960.0	110.0	47.7	SUPPLY
31	700.0	100.	966.3	266.3	115.4	
32	710.0	100.	964.4	254.4	110.2	

PIPE DATA

PIPE NO.	NODES FROM	TO	DIAM. IN.	LENGTH FT.	COEF	FLOW GPM	VEL. FT/SEC	HEAD LOSS
9	9	10	PUMP HEAD	206.0	FT	1922.	POWER	100. HP
10	10	11	18.0	10530.0	100.*	1922.	2.4	20.3
11	11	12	14.0	5280.0	100.*	1259.	2.6	15.8
12	12	13	10.0	5280.0	100.*	196.	0.8	2.6
21	21	22	10.0	5280.0	100.*	217.	0.9	3.1
22	22	23	12.0	5280.0	100.*	280.	0.8	2.1
23	23	24	10.0	8400.0	100.*	226.	0.9	5.4
24	25	24	18.0	200.0	100.*	165.	0.2	0.0
31	31	32	6.0	5280.0	100.*	43.	0.5	1.9
110	12	2	18.0	200.0	100.*	596.	0.8	0.0
111	11	21	10.0	5280.0	100.*	510.	2.1	15.3
112	12	22	12.0	5280.0	100.*	315.	0.9	2.6
113	13	23	8.0	5280.0	100.*	96.	0.6	2.1
121	21	31	8.0	5280.0	100.*	143.	0.9	4.3
122	22	32	6.0	5280.0	100.*	56.	0.6	3.1

```
  BEGIN SIMULATION  : ENTER 0, PRESS RETURN
  MODIFY, ENTER DATA:       1
  PRINT TIME DATA   :       2
  STORE TIME DATA   :       3
  RETRIEVE TIME DATA:       4
  PROGRAM CONTROL   :       8
  TERMINATE         :       9

1

TIME SIMULATION INPUT
TYPE KEYW FOR LIST OF KEYWORDS

T. KEYWORD IS (DURA) ENTER (KEYWORD) DATA LIST
24
T. KEYWORD IS (DURA) ENTER (KEYWORD) DATA LIST
STEP 24
TIME STEP DURATION    1.00 HOURS
T. KEYWORD IS (STEP) ENTER (KEYWORD) DATA LIST
USAGE 1 1 12
ENTER   12 VALUES
1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.5 1.4 1.3 1.2 1.1
T. KEYWORD IS (USAG) ENTER (KEYWORD) DATA LIST
USAGE 1 13 24
ENTER   12 VALUES
1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.5 0.6 0.7 0.8 0.9
T. KEYWORD IS (USAG) ENTER (KEYWORD) DATA LIST
SPATIAL 1  RANGE 11 32
T. KEYWORD IS (SPAT) ENTER (KEYWORD) DATA LIST
RATIO 1
T. KEYWORD IS (RATI) ENTER (KEYWORD) DATA LIST
TANK 25 130 80 2000 110
T. KEYWORD IS (TANK) ENTER (KEYWORD) DATA LIST
2 150 100 2000 120
T. KEYWORD IS (TANK) ENTER (KEYWORD) DATA LIST
9 0 0 0 0
T. KEYWORD IS (TANK) ENTER (KEYWORD) DATA LIST
PUMP 9 LEFT 2 110 140
T. KEYWORD IS (PUMP) ENTER (KEYWORD) DATA LIST
BEGIN 9 OFF
T. KEYWORD IS (BEGI) ENTER (KEYWORD) DATA LIST
FIRE 22 10 11 1000
T. KEYWORD IS (FIRE) ENTER (KEYWORD) DATA LIST
PNODE 2 25 10 12
T. KEYWORD IS (PNOD) ENTER (KEYWORD) DATA LIST
PLINK 110 24 10 9
T. KEYWORD IS (PLIN) ENTER (KEYWORD) DATA LIST
DETAIL OFF
T. KEYWORD IS (DETA) ENTER (KEYWORD) DATA LIST
END
```

When the time simulation menu reappears, print the time data by selecting option 2, "PRINT TIME DATA." Table 28-29 shows the entered time data. Now begin the simulation by selecting option 0, "BEGIN SIMULATION." The program produces two tables of output. Table 28-30 gives the first table of output showing the flows in the links specified with keyword PLINK and the heads of the nodes specified with keyword PNODE. The column with the heading "TIME" gives the time in hours corresponding to the time just before the hour, when water use changes have not yet been made. Negative flows in links indicate that the flow has reversed direction. Heads shown for tanks 2 and 25 are the hydraulic grade line at each node (i.e., the tank water level above the node added to the node elevation). Note that pump 9 turned on when the water level in tank 2 dropped to 110 (hydraulic grade line of 960). The water level then began rising except for when the fire at node 22 took place. When the water level in tank 2 rose to 140 (hydraulic grade line of 990), pump 9 turned off. The second table of output is given as Table 28-31. Minimum pressures and nodes where those pressures occurred are shown. For this system, the minimum pressure occurred at node 32 for each time. The table also displays tank water levels (level of water above the tank node) over the time simulation. The plus signs following the hours correspond to the beginning of the hour, after the loading factors and any fire flow have been taken into consideration. The minus signs following the hours correspond to the time just before the hour, when loading factor changes have not been made. Since tank water levels do not change right before and after the hour, they are only shown at times just before the hour. Note that the low pressure throughout the entire simulation occurred at time 11.00-, when the fire flow existed at node 22. After displaying the second table, the computer prompts:

ENTER NUMBER CORRESPONDING TO TIME STEP TO VIEW FLOWS AND PRESSURES FOR ENTIRE SYSTEM (ENTER N FOR NO VIEWING, R TO RETRIEVE TABLE)

If the user wishes to view the flows and pressures for the entire system at a particular time, he would enter the appropriate number (displayed in the first column of the table). Table 28-32 shows the output when 22 is entered (corresponding to the fire flow requirement at node 22 at time 11 hours). The balanced system for this time is shown.

28-43. Example 7. Consider the water system shown in plan view in Figure 28-11 and in profile in Figure 28-12. For the purpose of the extended period simulation, the water users in the system can be represented by five water use areas at nodes 16, 20, 21, 30, and 42. The topography is fairly flat except for the areas around node 42, which is 150 feet higher than the surrounding service areas. The system is supplied from a central pumping station equipped with three identical pumps in parallel (links 1, 2, and 3). They take water from the clearwell at the water treatment plant where the water surface level is maintained at 120 feet. The number of pumps running at the main pumping station is controlled by the water level in the tank at node 17. As the water level drops, more pumps automatically come on line. The area around node 42 is a separate pressure zone, served by a booster pumping station with two identical pumps (links 39 and 40). These are controlled by the water level in tank 43. While the service area around node 30 is in the lower pressure zone, it can receive water from the higher pressure zone

Table 28-29. Time Input Data for Example 6

TIME SIMULATION PARAMETERS

SIMULATION DURATION 24.00 HRS
TIME STEP SIZE 1.00 HRS
NUMBER OF TIME STEPS 24
RATIO OF OUTPUTS FROM SIMULATION 1.00

STEP	PATTERN 1
1	1.00
2	1.10
3	1.20
4	1.30
5	1.40
6	1.50
7	1.60
8	1.50
9	1.40
10	1.30
11	1.20
12	1.10
13	1.00
14	0.90
15	0.80
16	0.70
17	0.60
18	0.50
19	0.40
20	0.50
21	0.60
22	0.70
23	0.80
24	0.90

TANK DATA

NODE	MAX HT FT	MIN HT FT	AREA SQFT	INIT HT FT
25	130.0	80.0	2000.0	110.0
2	150.0	100.0	2000.0	120.0
9	CONSTANT HEAD		1E10	

(Continued)

Table 28-29. (Concluded)

FIRE EVENT DATA

NODE	START STEP	ENDING STEP	FLOW GPM
22	10	11	1000.0

NO LINKS OUT OF SERVICE
ALL NODES ASSIGNED USE PATTERN 1

PUMP CONTROLS

PUMP #	START STEP	END STEP	NODE #	ON LEVEL	OFF LEVEL	INITIAL STATUS
9			2	110.00	140.00	OFF

NODES ASSIGNED FOR OUTPUT

2
25
10
12

LINKS ASSIGNED FOR OUTPUT

110
24
10
9

DETAIL PRINTING OF TIME STEPS: OFF

Table 28-30. First Table of Time Output for Example 6

TIME HOURS	NODE 2 FT	NODE 25 FT	NODE 10 PSI	NODE 12 PSI	LINK 110 GPM 2 TO 12	LINK 24 GPM 24 TO 25	LINK 10 GPM 10 TO 11	LINK 9 GPM 9 TO 10
0.00	970.	960.	112.	117.	1264.	-236.	0.	0.
1.00	965.	959.	110.	115.	1169.	-331.	0.	0.
2.00	960.	957.	108.	113.	1111.	-539.	0.	0.
2.08	PUMP 9 : LEVEL. CONTROL, ON							
3.00	962.	955.	126.	114.	-527.	-343.	1983.	1983
4.00	964.	954.	126.	114.	-364	-341.	1977.	1977.
5.00	965.	952.	126.	115.	-230.	-356.	1974.	1974.
6.00	965.	951.	126.	115.	-105.	-381.	1975.	1975.
7.00	965.	949.	126.	115.	16.	-412.	1979.	1979.
8.00	966.	948.	126.	115.	-55.	-332.	1974.	1974.
9.00	966.	946.	126.	115.	-114.	-257.	1966.	1966.
10.00	967.	946.	127.	116.	-189.	-184.	1957	1957
10.00	FIRE AT NODE 22 ON							
11.00	965.	944.	126.	115.	406.	-408.	1984	1984
11.00	FIRE AT NODE 22 OFF							
12.00	967.	944.	127.	116.	-359.	-59.	1950.	1950.
13.00	969.	944.	128.	116.	-423.	6.	1934.	1934.
14.00	971.	944.	129.	117.	-480.	78.	1915.	1915.
15.00	973.	944.	130.	118.	-543.	145.	1895.	1895.
16.00	976.	945.	131.	119.	-612.	210.	1873.	1873.
17.00	979.	946.	132.	121.	-675.	274.	1849.	1850.
18.00	982.	948.	133.	122.	-736.	337.	1824.	1824.
19.00	985.	949.	134.	123.	-797.	399.	1797.	1797.
20.00	988.	951.	135.	125.	-667.	363.	1781.	1781.
21.00	990.	952.	135.	126.	-546.	323.	1769.	1769.
21.08	PUMP 9 : LEVEL. CONTROL, OFF							
22.00	985.	953.	119.	124.	1249.	199.	0.	0.
23.00	980.	953.	116.	121.	1291.	91.	0.	0.
24.00	974.	954.	114.	119.	1327.	-21.	0.	0.

Table 28-31. Second Table of Time Output for Example 6

TANK WATER LEVELS AND MINIMUM PRESSURES
OVER DURATION OF TIME SIMULATION

NUMBER	TIME	MIN.PR.	NODE	TANK WATER LEVELS		
				25	2	9
1	0.00+	108.0	32	110.0	120.0	0.0
2	1.00-	106.3	32	109.0	115.0	0.0
3	1.00+	105.6	32			
4	2.00-	104.1	32	107.3	110.0	0.0
5	2.00+	103.4	32			
6	3.00-	105.6	32	105.4	112.1	0.0
7	3.00+	104.8	32			
8	4.00-	105.2	32	103.9	113.7	0.0
9	4.00+	104.3	32			
10	5.00-	104.5	32	102.3	114.8	0.0
11	5.00+	103.6	32			
12	6.00-	103.6	32	100.7	115.4	0.0
13	6.00+	102.7	32			
14	7.00-	102.5	32	98.9	115.5	0.0
15	7.00+	103.5	32			
16	8.00-	103.5	32	97.5	115.7	0.0
17	8.00+	104.5	32			
18	9.00-	104.6	32	96.4	116.3	0.0
19	9.00+	105.6	32			
20	10.00-	105.8	32	95.6	117.1	0.0
21	10.00+	100.9	32			
22	11.00-	100.2	32	94.0	115.5	0.0
23	11.00+	106.9	32			
24	12.00-	107.4	32	93.7	117.0	0.0
25	12.00+	108.2	32			
26	13.00-	108.9	32	93.7	118.7	0.0
27	13.00+	109.6	32			
28	14.00-	110.4	32	93.9	120.8	0.0
29	14.00+	111.1	32			
30	15.00-	112.0	32	94.5	123.1	0.0
31	15.00+	112.6	32			
32	16.00-	113.6	32	95.3	125.7	0.0
33	16.00+	114.2	32			
34	17.00-	115.3	32	96.3	128.5	0.0
35	17.00+	115.7	32			
36	18.00-	116.9	32	97.6	131.6	0.0
37	18.00+	117.3	32			

(Continued)

Table 28-31. (Concluded)

38	19.00-	118.6	32	99.1	135.0	0.0
39	19.00+	118.3	32			
40	20.00-	119.4	32	100.6	137.8	0.0
41	20.00+	119.0	32			
42	21.00-	119.9	32	101.8	140.0	0.0
43	21.00+	119.4	32			
44	22.00-	115.4	32	102.8	135.4	0.0
45	22.00+	114.7	32			
46	23.00-	112.7	32	103.4	130.0	0.0
47	23.00+	112.0	32			
48	24.00-	109.9	32	103.5	124.4	0.0

when the pressure drops below 60 pounds per square inch (tank 31 nearly empty). The water users served at all of the nodes except 30 are domestic and commercial users whose water consumption rates vary, as shown in Figure 28-13. The water users at node 30 consist primarily of an industry that operates 24 hours a day and has a much more uniform consumption pattern, also shown in Figure 28-13. First, simulate the system for a 3-day (72-hour) period using 4-hour time steps, starting at 8 a.m., to observe normal system behavior. Next, determine what would happen if link 225 between node 20 and 22 was taken out of service for the 72-hour period. (The results for such a series of runs are shown beginning on page 28-111.) Note that when link 225 is taken out of service, the tank at node 21 drains during times of high water use during the 3-day period. The pressure does not drop any lower than 47 pounds per square inch, which should be acceptable. The results of the simulation for the case with and without link 225 are shown in Figures 28-14 and 28-15.

Table 28-32. Flows and Pressures at Time 11 hours for Example 6

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXAMPLE 6

NODE DATA

Page 1

NODE NO.	ELEV. FT.	OUTPUT GPM	E.G.L. FT.	PR.HEAD FT.	PRESSURE PSI	
2	850.0	-406.	965.5	115.5	50.0	SUPPLY
9	800.0	-1984.	800.0			RESERVOIR
10	710.0		999.7	289.7	125.5	
11	710.0	180.	978.1	268.1	116.2	
12	700.0	180.	965.4	265.4	115.0	
13	695.0	120.	956.9	261.9	113.5	
21	700.0	180.	951.4	251.4	108.9	
22	695.0	1240.	944.6	249.6	108.2	
23	690.0	180.	944.6	254.6	110.3	
24	670.0	480.	944.0	274.0	118.7	
25	850.0	-408.	944.0	94.0	40.7	SUPPLY
31	700.0	120.	944.8	244.8	106.0	
32	710.0	120.	941.2	231.2	100.2	

PIPE DATA

PIPE NO.	NODES FROM	NODES TO	DIAM. IN.	LENGTH FT.	COEF	FLOW GPM	VEL. FT/SEC	HEAD LOSS
9	9	10	PUMP HEAD	199.7	FT	1984.	POWER	100. HP
10	10	11	18.0	10530.0	100.*	1984.	2.5	21.6
11	11	12	14.0	5280.0	100.*	1115.	2.3	12.7
12	12	13	10.0	5280.0	100.*	372.	1.5	8.5
21	21	22	10.0	5280.0	100.*	328.	1.3	6.8
22	22	23	12.0	5280.0	100.*	3.	0.0	0.0
23	23	24	10.0	8400.0	100.*	72.	0.3	0.7
24	25	24	18.0	200.0	100.*	408.	0.5	0.0
31	31	32	6.0	5280.0	100.*	61.	0.7	3.6
110	2	12	18.0	200.0	100.*	406.	0.5	0.0
111	11	21	10.0	5280.0	100.*	689.	2.8	26.7
112	12	22	12.0	5280.0	100.*	972.	2.8	20.8
113	13	23	8.0	5280.0	100.*	252.	1.6	12.3
121	21	31	8.0	5280.0	100.*	181.	1.2	6.6
122	22	32	6.0	5280.0	100.*	59.	0.7	3.4

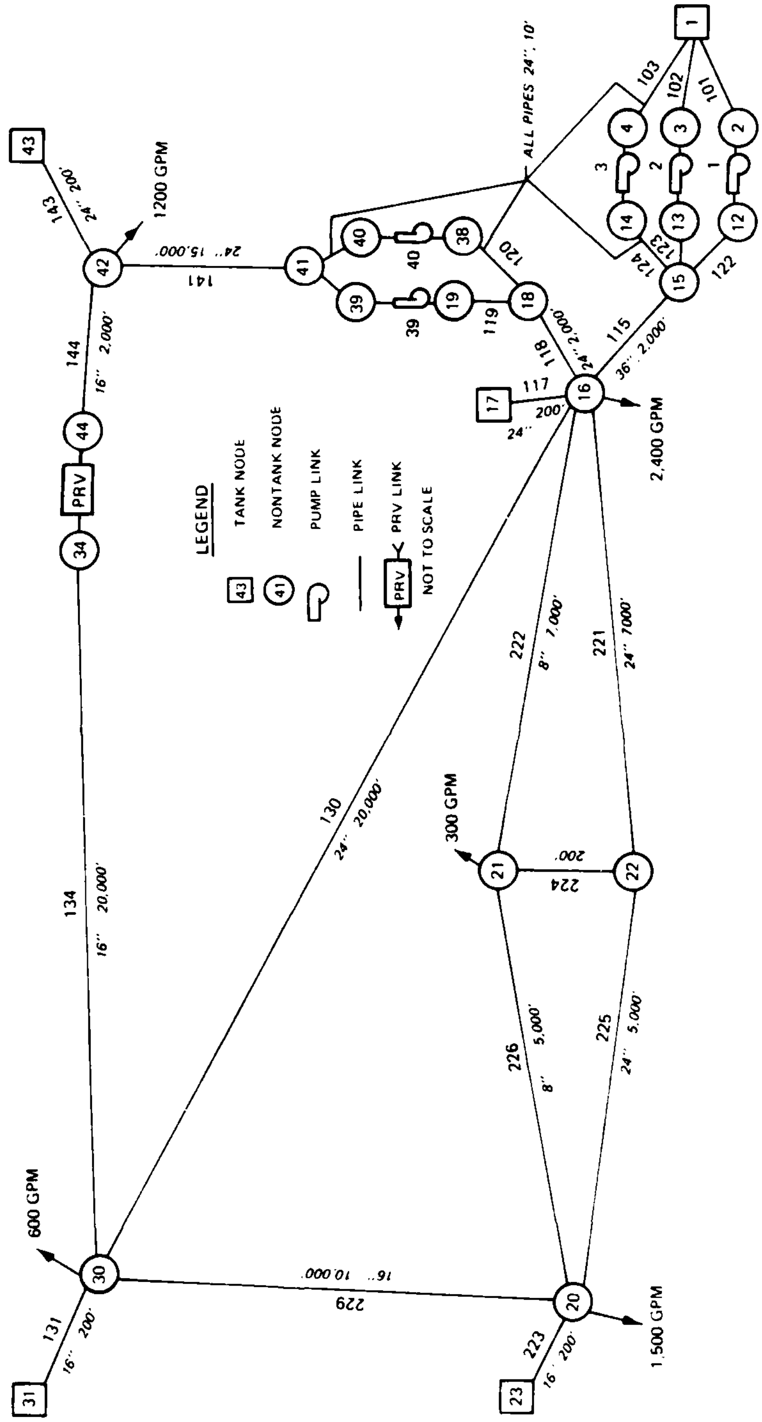

Figure 28-11. Plan view of system for Example 7

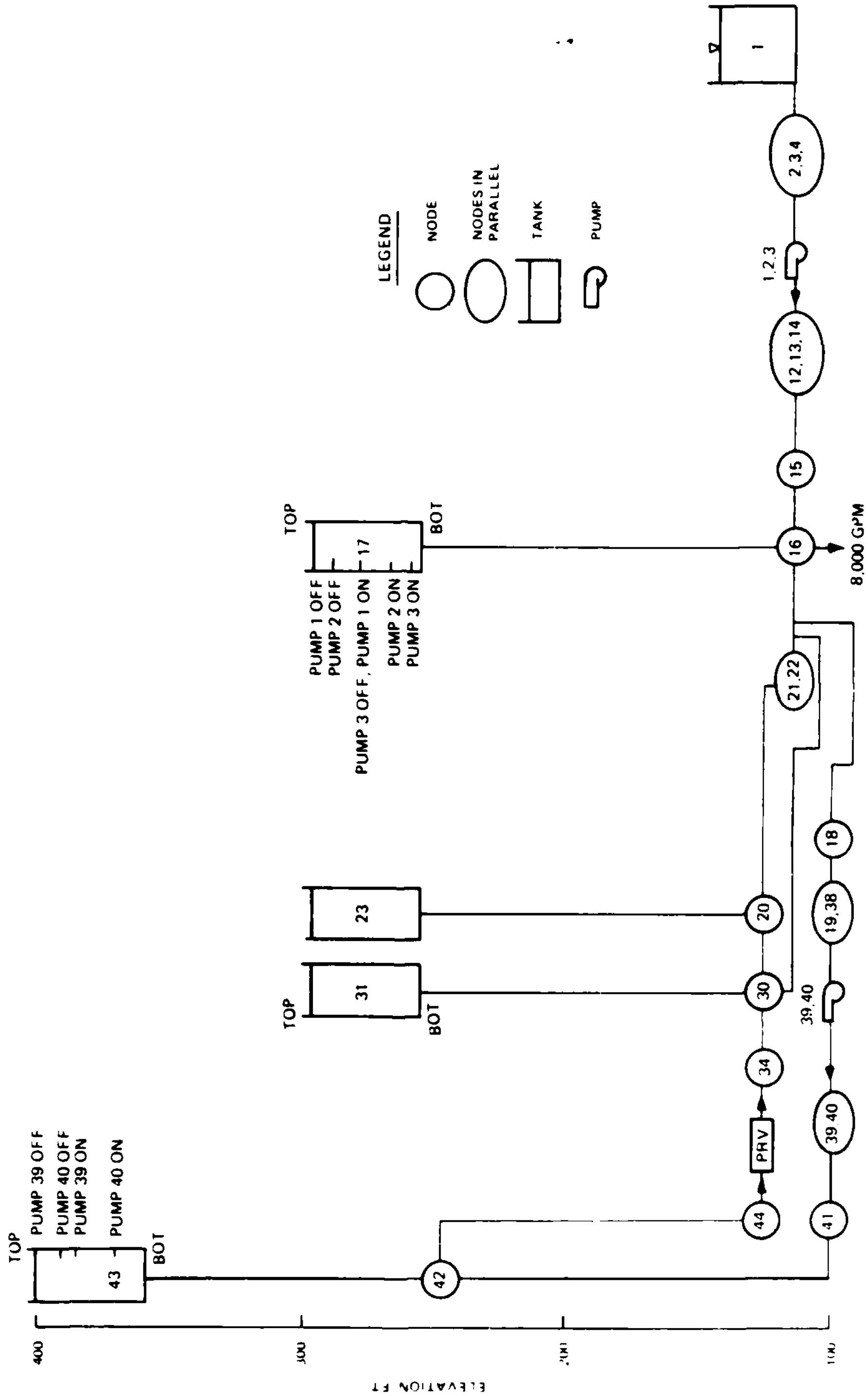

Figure 28-12. Profile view of system for Example 7

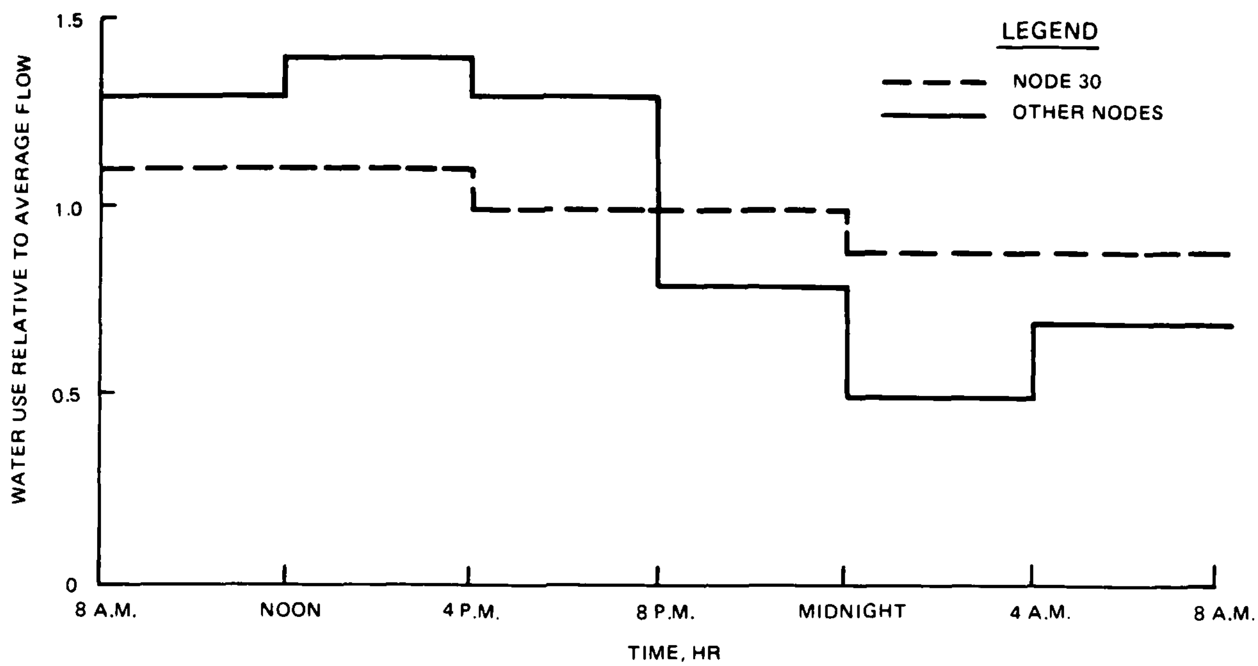

Figure 28-13. Water consumption patterns for Example 7

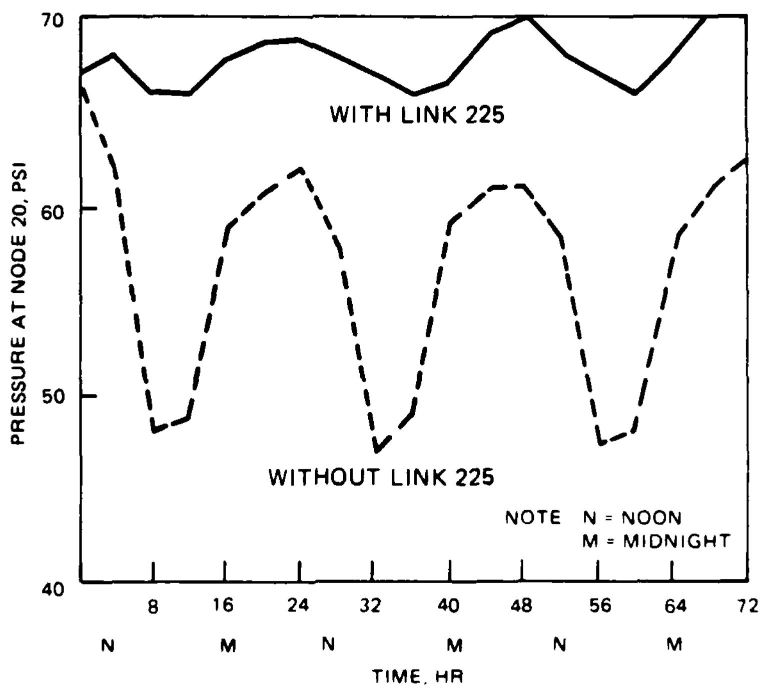

Figure 28-14. Variation in pressure at node 20

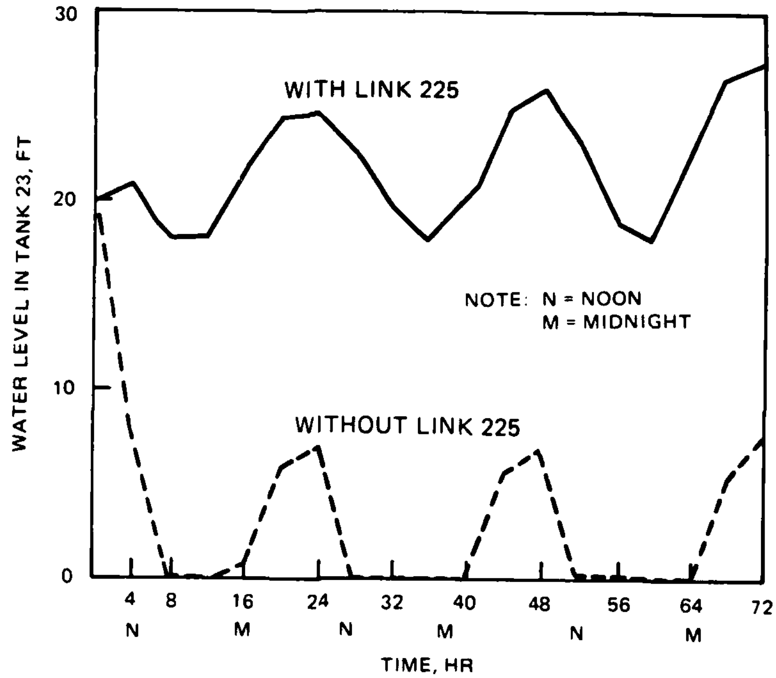

Figure 28-15. Variation of water level, tank 23

```
WADISO - WATER DISTRIBUTION SYSTEM OPTIMIZATION
VERSION:  JANUARY 9, 1987

MAX NODE NO = 300 NUMBER OF NODES = 200
MAX PIPE NO = 300 NUMBER OF PIPES = 200

PROGRAM CONTROL  :

     SIMULATION           :  ENTER 1 PRESS RETURN
     OPTIMIZATION         :        2
     COST DATA            :        3
     TIME SIMULATION      :        4
     TERMINATE PROGRAM    :        9

1
 SIMULATION ROUTINE

SELECT PROGRAM OPTION     :

     TO ENTER NEW JOB     :  ENTER 1 PRESS RETURN
     TO RETRIEVE DATA     :        2

1

STEADY STATE SIMULATION INPUT
TYPE KEYW FOR LIST OF KEYWORDS

S. KEYWORD IS JOB  ENTER (KEYWORD) DATA LIST
```

```
JOB  EXTENDED PERIOD NETWORK
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
PIPE 102 1 2 24 10
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
103 1 3 24 10
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
104 1 4 24 10
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
122 12 15 24 10
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
123 13 15 24 10
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
124 14 15 24 10
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
115 15 16 36 2000
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
117 16 17 24 200
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
118 16 18 24 2000
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
119 18 19 24 10
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
120 18 38 24 10
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
139 39 41 24 10
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
140 40 41 24 10
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
141 41 42 24 15000
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
143 42 43 24 200
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
144 42 44 16 2000
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
```

```
130 16 30 24 20000
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
134 30 34 16 10000
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
131 30 31 16 200
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
229 20 30 16 10000
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
223 20 23 16 200
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
221 16 22 24 7000
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
222 16 21 8 7000
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
224 21 22 8 200
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
225 20 22 24 5000
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
226 20 21 8 5000
S. KEYWORD IS PIPE  ENTER (KEYWORD) DATA LIST
PUMP 1 2 12
POINT  1 ON CHARACTERISTIC CURVE: ENTER DISCHARGE,   HEAD
5000 200
POINT  2 ON CHARACTERISTIC CURVE: ENTER DISCHARGE,   HEAD
E
PUMP COEFFICIENTS FOR PUMP   1.  Q IN CFS
         Q*Q            Q   CONSTANT
     -0.5372     -0.0002     266.7
S. KEYWORD IS PUMP  ENTER (KEYWORD) DATA LIST
PUMP 2 3 13
POINT  1 ON CHARACTERISTIC CURVE: ENTER DISCHARGE,   HEAD
5000 200
POINT  2 ON CHARACTERISTIC CURVE: ENTER DISCHARGE,   HEAD
E
PUMP COEFFICIENTS FOR PUMP  2.  Q IN CFS
         Q*Q            Q   CONSTANT
     -0.5372     -0.0002     266.7
```

```
S. KEYWORD IS PUMP  ENTER (KEYWORD) DATA LIST

PUMP 3 4 14
POINT  1 ON CHARACTERISTIC CURVE: ENTER DISCHARGE,   HEAD

5000 200
POINT  2 ON CHARACTERISTIC CURVE: ENTER DISCHARGE,   HEAD

E
PUMP COEFFICIENTS FOR PUMP   3.  Q IN CFS
         Q*Q            Q   CONSTANT
     -0.5372      -0.0002     266.7

S. KEYWORD IS PUMP  ENTER (KEYWORD) DATA LIST

PUMP 39 19 39
POINT  1 ON CHARACTERISTIC CURVE: ENTER DISCHARGE,   HEAD

2000 150
POINT  2 ON CHARACTERISTIC CURVE: ENTER DISCHARGE,   HEAD

E
PUMP COEFFICIENTS FOR PUMP  39.  Q IN CFS
         Q*Q            Q   CONSTANT
     -2.5181      -0.0003     200.0

S. KEYWORD IS PUMP  ENTER (KEYWORD) DATA LIST

PUMP 40 38 40
POINT  1 ON CHARACTERISTIC CURVE: ENTER DISCHARGE,   HEAD

2000 150
POINT  2 ON CHARACTERISTIC CURVE: ENTER DISCHARGE,   HEAD

E
PUMP COEFFICIENTS FOR PUMP  40.  Q IN CFS
         Q*Q            Q   CONSTANT
     -2.5181      -0.0003     200.0

S. KEYWORD IS PUMP  ENTER (KEYWORD) DATA LIST

PRV 34 44 34
ENTER PRESSURE SETTING

60.00

S. KEYWORD IS PRV   ENTER (KEYWORD) DATA LIST

COEF 80

S. KEYWORD IS COEF   ENTER (KEYWORD) DATA LIST

NODE

FOR NODE    1  ENTER ELEVATION, OUTPUT

100

FOR NODE    2  ENTER ELEVATION, OUTPUT

100

FOR NODE    3  ENTER ELEVATION, OUTPUT
```

```
100
FOR NODE   4  ENTER ELEVATION, OUTPUT
100
FOR NODE   12  ENTER ELEVATION, OUTPUT
100
FOR NODE   13  ENTER ELEVATION, OUTPUT
100
FOR NODE   14  ENTER ELEVATION, OUTPUT
100
FOR NODE   15  ENTER ELEVATION, OUTPUT
100
FOR NODE   16  ENTER ELEVATION, OUTPUT
100 2400
FOR NODE   17  ENTER ELEVATION, OUTPUT
260
FOR NODE   18  ENTER ELEVATION, OUTPUT
100
FOR NODE   19  ENTER ELEVATION, OUTPUT
100
FOR NODE   20  ENTER ELEVATION, OUTPUT
125 1500
FOR NODE   21  ENTER ELEVATION, OUTPUT
100 300
FOR NODE   22  ENTER ELEVATION, OUTPUT
100
FOR NODE   23  ENTER ELEVATION, OUTPUT
260
FOR NODE   30  ENTER ELEVATION, OUTPUT
125  600
FOR NODE   31  ENTER ELEVATION, OUTPUT
260
FOR NODE   34  ENTER ELEVATION, OUTPUT
125
FOR NODE   38  ENTER ELEVATION, OUTPUT
```

```
100
FOR NODE   39  ENTER ELEVATION, OUTPUT
100
FOR NODE   40  ENTER ELEVATION, OUTPUT
100
FOR NODE   41  ENTER ELEVATION, OUTPUT
100
FOR NODE   42  ENTER ELEVATION, OUTPUT
250 1200
FOR NODE   43  ENTER ELEVATION, OUTPUT
360
FOR NODE   44  ENTER ELEVATION, OUTPUT
125
S. KEYWORD IS TANK   ENTER (KEYWORD) DATA LIST
TANK 1 20
S. KEYWORD IS TANK   ENTER (KEYWORD) DATA LIST
23 20
S. KEYWORD IS TANK   ENTER (KEYWORD) DATA LIST
17 20
S. KEYWORD IS TANK   ENTER (KEYWORD) DATA LIST
31 20
S. KEYWORD IS TANK   ENTER (KEYWORD) DATA LIST
43 20
S. KEYWORD IS TANK   ENTER (KEYWORD) DATA LIST
END
SELECT PROGRAM OPTION :
     BALANCE            :  ENTER 0 OR 0C PRESS RETURN
     MODIFY SYSTEM      :        1
     PRINT INPUT        :        2    2C
     STORE DATA         :        3
     RETRIEVE DATA      :        4
     PRINT OUTPUT       :        6    6C
     PROGRAM CONTROL    :        8
     TERMINATE PROGRAM  :        9
3
ENTER FILE NAME
A:EXTS
```

```
SELECT PROGRAM OPTION :

     BALANCE              : ENTER 0 OR 0C PRESS RETURN
     MODIFY SYSTEM        :        1
     PRINT INPUT          :        2    2C
     STORE DATA           :        3
     RETRIEVE DATA        :        4
     PROGRAM CONTROL      :        8
     TERMINATE PROGRAM    :        9

0C


ACCURACY LIMITS:   2.0 PSI;     10.0 GPM

ESTIMATED MAXIMUM ERRORS:

ITERATION #  1 :    102.3 PSI AT NODE   44;  39388. GPM AT NODE       2
ITERATION #  2 :     83.0 PSI AT NODE   39;   5875. GPM AT NODE      15
ITERATION #  3 :      7.5 PSI AT NODE   44;   2231. GPM AT NODE      15
ITERATION #  4 :      1.0 PSI AT NODE   14;    937. GPM AT NODE      15
ITERATION #  5 :      0.4 PSI AT NODE   14;    413. GPM AT NODE      15
ITERATION #  6 :      0.2 PSI AT NODE   14;    186. GPM AT NODE      15
ITERATION #  7 :      0.1 PSI AT NODE   14;     85. GPM AT NODE      15
ITERATION #  8 :      0.0 PSI AT NODE   14;     39. GPM AT NODE      15
ITERATION #  9 :      0.0 PSI AT NODE   14;     18. GPM AT NODE      15
ITERATION # 10 :      0.0 PSI AT NODE   12;      8. GPM AT NODE      15

SYSTEM IS BALANCED


     PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB:   EXTENDED PERIOD NETWORK
```

NODE DATA — PAGE 1

NODE NO.	ELEV. FT.	OUTPUT GPM	E.G.L. FT.	PR.HEAD FT.	PRESSURE PSI	
1	100.0	-17627.	120.0	20.0	8.7	SUPPLY
2	100.0		119.9	19.9	8.6	
3	100.0		119.9	19.9	8.6	
4	100.0		119.9	19.9	8.6	
12	100.0		294.7	194.7	84.4	
13	100.0		294.7	194.7	84.4	
14	100.0		294.7	194.7	84.4	
15	100.0		294.7	194.7	84.4	
16	100.0	2400.	282.6	182.6	79.1	
17	260.0	9164.	280.0	20.0	8.7	SUPPLY
18	100.0		276.7	176.7	76.6	
19	100.0		276.7	176.7	76.6	
20	125.0	1500.	279.9	154.9	67.1	

NODE NO.	ELEV. FT.	OUTPUT GPM	E.G.L. FT.	PR.HEAD FT.	PRESSURE PSI	
21	100.0	300.	280.1	180.1	78.0	
22	100.0		280.7	180.7	78.3	
23	260.0	-541.	280.0	20.0	8.7	SUPPLY
30	125.0	600.	280.0	155.0	67.2	
31	260.0	95.	280.0	20.0	8.7	SUPPLY
34	125.0		280.0	155.0	67.2	
38	100.0		276.7	176.7	76.6	
39	100.0		424.2	324.2	140.5	
40	100.0		424.2	324.2	140.5	
41	100.0		424.2	324.2	140.5	
42	250.0	1200.	380.3	130.3	56.5	
43	360.0	2900.	380.0	20.0	8.7	SUPPLY
44	125.0		380.3	255.3	110.6	

JOB: EXTENDED PERIOD NETWORK

PIPE DATA

PAGE 2

PIPE NO.	NODES FROM	NODES TO	DIAM. IN.	LENGTH FT.	COEF	FLOW GPM	VEL. FT/SEC	HEAD LOSS
1	2	12	PUMP HEAD	174.8	FT	5870.	POWER	259.HP
2	3	13	PUMP HEAD	174.8	FT	5870.	POWER	259.HP
3	4	14	PUMP HEAD	174.8	FT	5870.	POWER	259.HP
34	44	34	PRV AT	60.0	PSI	CLOSED		
39	19	39	PUMP HEAD	147.5	FT	2050.	POWER	76.HP
40	38	40	PUMP HEAD	147.5	FT	2050.	POWER	76.HP
102	1	2	24.0	10.0	80.*	5876.	4.2	0.1
103	1	3	24.0	10.0	80.*	5876.	4.2	0.1
104	1	4	24.0	10.0	80.*	5876.	4.2	0.1
115	15	16	36.0	2000.0	80.*	17619.	5.6	12.1
117	16	17	24.0	200.0	80.*	9164.	6.5	2.6
118	16	18	24.0	2000.0	80.*	4100.	2.9	5.9
119	18	19	24.0	10.0	80.*	2051.	1.5	0.0
120	18	38	24.0	10.0	80.*	2051.	1.5	0.0
122	12	15	24.0	10.0	80.*	5876.	4.2	0.1
123	13	15	24.0	10.0	80.*	5876.	4.2	0.1
124	14	15	24.0	10.0	80.*	5876.	4.2	0.1
130	16	30	24.0	20000.0	80.*	762.	0.5	2.6
131	30	31	16.0	200.0	80.*	95.	0.2	0.0
134	30	34	16.0	10000.0	80.*	0.	0.0	0.0
139	39	41	24.0	10.0	80.*	2051.	1.5	0.0
140	40	41	24.0	10.0	80.*	2051.	1.5	0.0
141	41	42	24.0	15000.0	80.*	4100.	2.9	43.9
143	42	43	24.0	200.0	80.*	2900.	2.1	0.3
144	42	44	16.0	2000.0	80.*	0.	0.0	0.0
221	16	22	24.0	7000.0	80.*	1121.	0.8	1.9
222	16	21	8.0	7000.0	80.*	74.	0.5	2.5
223	23	20	16.0	200.0	80.*	541.	0.9	0.1

PIPE DATA PAGE 2

PIPE NO.	NODES FROM	NODES TO	DIAM. IN.	LENGTH FT.	COEF	FLOW GPM	VEL. FT/SEC	HEAD LOSS
224	22	21	8.0	200.0	80.*	246.	1.6	0.7
225	22	20	24.0	5000.0	80.*	875.	0.6	0.8
226	21	20	8.0	5000.0	80.*	20.	0.1	0.2
229	30	20	16.0	10000.0	80.*	67.	0.1	0.1

```
SELECT PROGRAM OPTION :

     BALANCE            : ENTER 0 OR OC PRESS RETURN
     MODIFY SYSTEM      :       1
     PRINT INPUT        :       2     2C
     STORE DATA         :       3
     RETRIEVE DATA      :       4
     PRINT OUTPUT       :       6     6C
     PROGRAM CONTROL    :       8
     TERMINATE PROGRAM  :       9

8

PROGRAM CONTROL :

     SIMULATION         : ENTER  1  PRESS RETURN
     OPTIMIZATION       :        2
     COST DATA          :        3
     TIME SIMULATION    :        4
     TERMINATE PROGRAM  :        9

4

TIME SIMULATION MENU

SELECT PROGRAM OPTION:

     BEGIN SIMULATION     : ENTER 0, PRESS RETURN
     MODIFY,ENTER DATA    :       1
     PRINT TIME DATA      :       2
     STORE TIME DATA      :       3
     RETRIEVE TIME DATA   :       4
     PROGRAM CONTROL      :       8
     TERMINATE            :       9

1

TIME SIMULATION INPUT
TYPE KEYW FOR LIST OF KEYWORDS

T. KEYWORD IS (DURA) ENTER (KEYWORD) DATA LIST

DURA 72

T. KEYWORD IS (DURA) ENTER (KEYWORD) DATA LIST
```

```
STEP 18
TIME STEP SIZE   4.00 HOURS
T. KEYWORD IS (STEP) ENTER (KEYWORD) DATA LIST
PUMP 1 LEFT 17 20 38
T. KEYWORD IS (PUMP) ENTER (KEYWORD) DATA LIST
PUMP 2 LEFT 17 10 30
T. KEYWORD IS (PUMP) ENTER (KEYWORD) DATA LIST
PUMP 3 LEFT 17  5 20
T. KEYWORD IS (PUMP) ENTER (KEYWORD) DATA LIST
PUMP 39 LEFT 43 25 38
T. KEYWORD IS (PUMP) ENTER (KEYWORD) DATA LIST
PUMP 40 LEFT 43 10 30
T. KEYWORD IS (PUMP) ENTER (KEYWORD) DATA LIST
TANK  1 25  0 0 20
T. KEYWORD IS (TANK) ENTER (KEYWORD) DATA LIST
TANK 17 40  0 30000 30
T. KEYWORD IS (TANK) ENTER (KEYWORD) DATA LIST
TANK 23 40  0  3000 20
T. KEYWORD IS (TANK) ENTER (KEYWORD) DATA LIST
TANK 31 40  0  3000 20
T. KEYWORD IS (TANK) ENTER (KEYWORD) DATA LIST
TANK 43 40  0 6000 30
T. KEYWORD IS (TANK) ENTER (KEYWORD) DATA LIST
USAG 2 1 6
ENTER    6 VALUES
1.3 1.4 1.3 .8 .5 .7
T. KEYWORD IS (USAG) ENTER (KEYWORD) DATA LIST
USAGE  2 7 12
ENTER    6 VALUES
1.3 1.4 1.3 .8 .5 .7
T. KEYWORD IS (USAG) ENTER (KEYWORD) DATA LIST
USAGE 2 13 18
ENTER    6 VALUES
1.3 1.4 1.3 .8 .5 .7
```

```
T. KEYWORD IS (USAG) ENTER (KEYWORD) DATA LIST

USAG 3 1 6
ENTER     6 VALUES

1.1 1.1 1.0 1.0 0.9 0.9

T. KEYWORD IS (USAG) ENTER (KEYWORD) DATA LIST

USAG 3 7 12
ENTER     6 VALUES

1.1 1.1 1.0 1.0 0.9 0.9

T. KEYWORD IS (USAG) ENTER (KEYWORD) DATA LIST
USAG 3 13 18
ENTER   6 VALUES

1.1 1.1 1.0 1.0 0.9 0.9

T. KEYWORD IS (USAG) ENTER (KEYWORD) DATA LIST

SPAT 2 RANG 1 29

T. KEYWORD IS (SPAT) ENTER (KEYWORD) DATA LIST

SPAT 2 RANG 31 43

T. KEYWORD IS (SPAT) ENTER (KEYWORD) DATA LIST

SPAT 3 NODE 30

T. KEYWORD IS (SPAT) ENTER (KEYWORD) DATA LIST

PNOD 16 17 20 23 30 42 43

T. KEYWORD IS (PNOD) ENTER (KEYWORD) DATA LIST

PLIN 221 229

T. KEYWORD IS (PLIN) ENTER (KEYWORD) DATA LIST

END
DEFAULT ASSIGNED TO PATTERN 1

TANK    1 IS CONSTANT HEAD TANK
RATIO SET TO 1

TIME SIMULATION MENU

SELECT PROGRAM OPTION:

     BEGIN SIMULATION    : ENTER 0, PRESS RETURN
     MODIFY,ENTER DATA   :       1
     PRINT TIME DATA     :       2
     STORE TIME DATA     :       3
     RETRIEVE TIME DATA  :       4
     PROGRAM CONTROL     :       8
     TERMINATE           :       9

2
```

TIME SIMULATION PARAMETERS

SIMULATION DURATION 72.00 HRS
TIME STEP SIZE 4.00 HRS
NUMBER OF TIME STEPS 18
RATIO OF OUTPUTS FROM SIMULATION 1.00

	PATTERN		
STEP	1	2	3
1	1.00	1.30	1.10
2	1.10	1.40	1.10
3	1.20	1.30	1.00
4	1.30	0.80	1.00
5	1.40	0.50	0.90
6	1.50	0.70	0.90
7	1.60	1.30	1.10
8	1.50	1.40	1.10
9	1.40	1.30	1.00
10	1.30	0.80	1.00
11	1.20	0.50	0.90
12	1.10	0.70	0.90
13	1.00	1.30	1.10
14	0.90	1.40	1.10
15	0.80	1.30	1.00
16	0.70	0.80	1.00
17	0.60	0.50	0.90
18	0.50	0.70	0.90

TANK DATA

NODE	MAX HT FT	MIN HT FT	AREA SQFT	INIT HT FT
23	40.0	0.0	3000.0	20.0
31	40.0	0.0	3000.0	20.0
43	40.0	0.0	6000.0	30.0
17	40.0	0.0	30000.0	30.0
1	CONSTANT HEAD		1E10	

NO FIRES SPECIFIED

NO LINKS OUT OF SERVICE

NODE	USAGE PATTERN
16	2
20	2
21	2
30	3
42	2

PUMP CONTROLS

PUMP #	START STEP	END STEP	NODE #	ON LEVEL	OFF LEVEL	INITIAL STATUS
1			17	20.00	38.00	ON
2			17	10.00	30.00	ON
3			17	5.00	20.00	ON
39			43	25.00	38.00	ON
40			43	10.00	30.00	ON

NODES ASSIGNED FOR PRINT OUT
16
17
20
23
30
42
43

LINKS ASSIGNED FOR PRINT OUT
221
229

DETAIL PRINTING OF TIME STEPS: OFF

TIME SIMULATION MENU

SELECT PROGRAM OPTION:

```
BEGIN SIMULATION     : ENTER 0,  PRESS RETURN
MODIFY,ENTER DATA    :       1
PRINT TIME DATA      :       2
STORE TIME DATA      :       3
RETRIEVE TIME DATA   :       4
PROGRAM CONTROL      :       8
TERMINATE            :       9
```

3

ENTER FILE NAME

A:EXTT

TIME SIMULATION MENU

SELECT PROGRAM OPTION:

```
     BEGIN SIMULATION      : ENTER 0,  PRESS RETURN
     MODIFY,ENTER DATA     :       1
     PRINT TIME DATA       :       2
     STORE TIME DATA       :       3
     RETRIEVE TIME DATA    :       4
     PROGRAM CONTROL       :       8
     TERMINATE             :       9
```

0
0.00 PUMP 3 : LEVEL CONTROL, OFF

TIME HOURS	NODE 16 PSI	NODE 17 FT	NODE 20 PSI	NODE 23 FT	NODE 30 PSI	NODE 42 PSI	NODE 43 FT	LINK 221 GPM 16 TO 22	LINK 229 GPM 20 TO 30
0.00	82.	290.	67.	280.	67.	61.	390.	2217.	-96.
0.00	PUMP 2 : LEVEL CONTROL, OFF								
0.00	PUMP 40 : LEVEL CONTROL, OFF								
4.00	81.	287.	68.	281.	69.	63.	395.	1583.	-482.
7.09	PUMP 39 : LEVEL CONTROL, OFF								
8.00	80.	285.	66.	278.	68.	63.	396.	1847.	-411.
12.00	80.	285.	66.	278.	67.	60.	388.	1823.	-355.
14.06	PUMP 39 : LEVEL CONTROL, ON								
16.00	80.	285.	68.	282.	68.	60.	389.	1231.	-198.
19.65	PUMP 39 : LEVEL CONTROL, OFF								
20.00	81.	286.	69.	285.	69.	64.	398.	877.	111.
24.00	82.	289.	69.	285.	69.	62.	393.	1335.	-103.
27.97	PUMP 39 : LEVEL CONTROL, ON								
28.00	82.	289.	68.	282.	69.	58.	385.	1783.	-363.
32.00	81.	286.	67.	280.	68.	60.	390.	1732.	-412.
36.00	80.	284.	66.	278.	68.	63.	394.	1651.	-399.
37.94	PUMP 39 : LEVEL CONTROL, OFF								
40.00	80.	285.	67.	281.	68.	63.	395.	1400.	-203.
44.00	81.	288.	69.	285.	70.	62.	392.	1172.	-241.
48.00	82.	290.	70.	286.	70.	60.	388.	1330.	-142.
49.31	PUMP 39 : LEVEL CONTROL, ON								
52.00	82.	289.	68.	283.	70.	60.	389.	1645.	-400.
56.00	80.	286.	67.	279.	68.	62.	393.	1816.	-452.
60.00	80.	284.	66.	278.	68.	64.	398.	1652.	-401.
60.23	PUMP 39: LEVEL CONTROL, OFF								
64.00	80.	285.	68.	282.	68.	62.	393.	1271.	191
68.00	82.	288.	70.	287.	69.	61.	390.	880.	306.
72.00	83.	291.	70.	288.	70.	59.	385.	1188.	187.

TANK WATER LEVELS AND MINIMUM PRESSURES
OVER DURATION OF TIME SIMULATION

NUMBER	TIME	MIN.PR.	NODE	TANK WATER LEVELS			
				23	31	43	17
1	0.00+	8.6	3	20.0	20.0	30.0	30.0
2	4.00-	8.6	2	21.3	25.4	35.1	26.5
3	4.00+	8.6	2				
4	8.00-	8.6	2	17.9	20.9	36.0	24.8
5	8.00+	8.6	2				
6	12.00-	8.6	2	18.1	20.4	27.6	24.9
7	12.00+	8.6	2				
8	16.00-	8.6	2	22.0	22.7	29.0	25.3
9	16.00+	8.6	2				
10	20.00-	8.6	2	24.7	24.5	37.8	26.2
11	20.00+	8.6	2				
12	24.00-	8.6	2	25.0	25.2	33.2	28.8
13	24.00+	8.6	2				
14	28.00-	8.6	2	22.2	24.6	24.9	29.0
15	28.00+	8.6	2				
16	32.00-	8.6	2	19.8	22.8	29.6	26.1
17	32.00+	8.6	2				
18	36.00-	8.6	2	18.2	21.0	34.4	23.9
19	36.00+	8.6	2				
20	40.00-	8.6	2	20.6	21.4	35.4	24.8
21	40.00+	8.6	2				
22	44.00-	8.6	2	24.6	25.9	32.2	27.6
23	44.00+	8.6	2				
24	48.00-	8.6	2	26.3	26.7	27.6	30.1
25	48.00+	8.6	2				
26	52.00-	8.6	2	22.8	25.6	28.6	28.5
27	52.00+	8.6	2				
28	56.00-	8.6	2	19.0	22.6	33.1	25.9
29	56.00+	8.6	2				
30	60.00-	8.6	2	18.0	20.8	37.6	23.7
31	60.00+	8.6	2				
32	64.00-	8.6	2	22.1	21.2	33.2	25.4
33	64.00+	8.6	2				
34	68.00-	8.6	2	26.8	24.9	30.0	28.3
35	68.00+	8.6	2				
36	72.00-	8.6	2	27.7	26.9	25.5	30.7

ENTER NUMBER CORRESPONDING TO TIME STEP TO VIEW FLOWS AND PRESSURES FOR
ENTIRE SYSTEM (ENTER N FOR NO VIEWING, R TO RETRIEVE TABLE)
N

TIME SIMULATION MENU

```
SELECT PROGRAM OPTION:

     BEGIN SIMULATION     : ENTER 0, PRESS RETURN
     MODIFY,ENTER DATA    :        1
     PRINT TIME DATA      :        2
     STORE TIME DATA      :        3
     RETRIEVE TIME DATA   :        4
     PROGRAM CONTROL      :        8
     TERMINATE            :        9

1

TIME SIMULATION INPUT
TYPE KEYW FOR LIST OF KEYWORDS

T. KEYWORD IS (DURA) ENTER (KEYWORD) DATA LIST

EXCL 225

T. KEYWORD IS (EXCL) ENTER (KEYWORD) DATA LIST

END

TIME SIMULATION MENU

SELECT PROGRAM OPTION:

     BEGIN SIMULATION     : ENTER 0, PRESS RETURN
     MODIFY,ENTER DATA    :        1
     PRINT TIME DATA      :        2
     STORE TIME DATA      :        3
     RETRIEVE TIME DATA   :        4
     PROGRAM CONTROL      :        8
     TERMINATE            :        9

0
 0.00       PUMP   3 : LEVEL CONTROL, OFF


        NODE     NODE    NODE    NODE    NODE    NODE    NODE    LINK     LINK
 TIME    16       17      20      23      30      42      43      221      229
HOURS   PSI       FT     PSI      FT     PSI     PSI      FT      GPM      GPM
                                                                   16       20
                                                                   TO       TO
                                                                   22       30
 0.00    82.     290.     67.    280.     67.     61.    390.     480.    -212.
 0.00      PUMP   2 : LEVEL CONTROL, OFF
 0.00      PUMP  40 : LEVEL CONTROL, OFF
 4.00    82.     288.     62.    268.     68.     63.    395.     550.    -929.
 7.01      PUMP  39 : LEVEL CONTROL, OFF
 7.40      TANK  23 : DISCONNECTED EMPTY
```

8.00	81.	287.	48.	260.	66.	63.	396.	722.	-1682.
12.00	81.	287.	49.	260.	64.	59.	387.	694.	-1536.
13.14	TANK	23 : CONNECTED							
13.88	PUMP	39 : LEVEL CONTROL, ON							
16.00	81.	288.	59.	261.	65.	60.	389.	468.	-997.
19.41	PUMP	39 : LEVEL CONTROL, OFF							
20.00	82.	288.	61.	266.	66.	64.	398.	369.	-874.
24.00	83.	291.	62.	267.	67.	62.	393.	425.	-920.
27.87	PUMP	39 : LEVEL CONTROL, ON							
28.00	83.	291.	58.	260.	67.	59.	385.	610.	-1148.
28.04	TANK	23 : DISCONNECTED EMPTY							
32.00	82.	289.	47.	260.	64.	61.	390.	740.	-1663.
36.00	81.	286.	49.	260.	63.	63.	395.	691.	-1539.
37.59	TANK	23 : CONNECTED							
37.59	PUMP	39 : LEVEL CONTROL, OFF							
40.00	81.	287.	59.	260.	65.	63.	395.	466.	-969.
44.00	82.	290.	61.	266.	66.	61.	392.	377.	-867.
48.00	83.	292.	61.	267.	68.	59.	387.	432.	-964.
49.05	PUMP	39 : LEVEL CONTROL, ON							
52.00	82.	290.	58.	260.	67.	60.	389.	605.	-1165.
52.08	TANK	23 : DISCONNECTED EMPTY							
56.00	81.	288.	47.	260.	64.	62.	394.	740.	-1662.
59.66	PUMP	39 : LEVEL CONTROL, OFF							
60.00	80.	286.	48.	260.	63.	64.	397.	692.	-1537.
64.00	81.	287.	59.	260.	65.	62.	392.	457.	-910.
64.00	TANK	23 : CONNECTED							
68.00	83.	290.	61.	266.	66.	60.	389.	381.	-894.
71.51	PUMP	39 : LEVEL CONTROL, ON							
72.00	83.	292.	62.	267.	68.	59.	386.	431.	-956.

TANK WATER LEVELS AND MINIMUM PRESSURES
OVER DURATION OF TIME SIMULATION

NUMBER	TIME	MIN.PR.	NODE	TANK WATER LEVELS			
				23	31	43	17
1	0.00+	8.6	3	20.0	20.0	30.0	30.0
2	4.00-	8.6	2	7.8	21.2	35.0	28.3
3	4.00+	8.6	2				
4	8.00-	8.6	2	0.0	17.1	35.8	27.0
5	8.00+	8.6	2				
6	12.00-	8.6	2	0.0	12.1	27.4	27.5
7	12.00+	8.6	2				
8	16.00-	8.6	2	0.5	15.9	29.5	27.8
9	16.00+	8.6	2				
10	20.00-	8.6	2	5.9	18.0	37.5	28.4
11	20.00+	8.6	2				
12	24.00-	8.6	2	7.0	20.3	33.0	30.8
13	24.00+	8.6	2				

14	28.00-	8.6	2	0.0	19.9	25.1	31.3
15	28.00+	8.6	2				
16	32.00-	8.6	2	0.0	13.0	30.0	28.5
17	32.00+	8.6	2				
18	36.00-	8.6	2	0.0	11.3	35.0	26.0
19	36.00+	8.6	2				
20	40.00-	8.6	2	0.1	14.7	34.9	26.9
21	40.00+	8.6	2				
22	44.00-	8.6	2	5.7	17.6	31.7	29.7
23	44.00+	8.6	2				
24	48.00-	8.6	2	6.8	21.3	27.2	31.9
25	48.00+	8.6	2				
26	52.00-	8.6	2	0.1	20.5	29.1	30.4
27	52.00+	8.6	2				
28	56.00-	8.6	2	0.0	12.3	33.7	27.9
29	56.00+	8.6	2				
30	60.00-	8.6	2	0.0	10.7	37.3	25.6
31	60.00+	8.6	2				
32	64.00-	8.6	2	0.0	15.2	32.2	27.4
33	64.00+	8.6	2				
34	68.00-	8.6	2	5.5	18.1	28.9	30.2
35	68.00+	8.6	2				
36	72.00-	8.6	2	7.1	21.3	26.1	32.0

ENTER NUMBER CORRESPONDING TO TIME STEP TO VIEW FLOWS AND PRESSURES FOR ENTIRE SYSTEM (ENTER N FOR NO VIEWING, R TO RETRIEVE TABLE)
18

OUTPUT FOR TIME 36:00 HOURS

LOADINGS

PATTERN	LOADING FACTOR
2	1.3
3	1.0

FLOWS AND PRESSURES

PIPE NETWORK ANALYSIS AND OPTIMIZATION

JOB: EXTENDED PERIOD NETWORK

NODE DATA PAGE 1

NODE NO.	ELEV. FT.	OUTPUT GPM	E.G.L. FT.	PR.HEAD FT.	PRESSURE PSI	
1	100.0	-6088.	120.0	20.0	8.7	SUPPLY
2	100.0		119.9	19.9	8.6	
3	100.0		120.0	20.0	8.7	
4	100.0		120.0	20.0	8.7	
12	100.0		287.6	187.6	81.3	
13	100.0		287.5	187.5	81.2	

NODE DATA PAGE 1

NODE NO.	ELEV. FT.	OUTPUT GPM	E.G.L. FT.	PR.HEAD FT.	PRESSURE PSI	
14	100.0		287.5	187.5	81.2	
15	100.0		287.5	187.5	81.2	
16	100.0	3120.	285.8	185.8	80.5	
17	260.0	-2160.	286.0	26.0	11.3	SUPPLY
18	100.0		283.6	183.6	79.6	
19	100.0		283.6	183.6	79.6	
20	125.0	1950.	237.0	112.0	48.5	
21	100.0	390.	280.5	180.5	78.2	
22	100.0		285.1	185.1	80.2	
23	260.0	0.	260.0			RESERVOIR
30	125.0	600.	271.3	146.3	63.4	
31	260.0	-211.	271.3	11.3	4.9	SUPPLY
34	125.0		271.3	146.3	63.4	
38	100.0		283.6	183.6	79.6	
39	100.0		411.4	311.4	134.9	
40	100.0		411.4	311.4	134.9	
41	100.0		411.4	311.4	134.9	
42	250.0	1560.	395.0	145.0	62.8	
43	360.0	846.	395.0	35.0	15.2	SUPPLY
44	125.0		395.0	270.0	117.0	

JOB: EXTENDED PERIOD NETWORK

PIPE DATA PAGE 2

PIPE NO.	NODES FROM	TO	DIAM. IN.	LENGTH FT.	COEF	FLOW GPM	VEL. FT/SEC	HEAD LOSS
1	2	12	PUMP HEAD	167.6	FT	6094.	POWER	258.HP
2	3	13	PUMP HEAD	167.5	FT	0.	POWER	0.HP
3	4	14	PUMP HEAD	167.5	FT	0.	POWER	0.HP
34	44	34	PRV AT	60.0	PSI	CLOSED		
39	19	39	PUMP HEAD	127.7	FT	2404.	POWER	78.HP
40	38	40	PUMP HEAD	127.7	FT	0.	POWER	0.HP
102	1	2	24.0	10.0	80.*	6088.	4.3	0.1
103	3	1	24.0	10.0	80.*	0.	0.0	0.0
104	4	1	24.0	10.0	80.*	0.	0.0	0.0
115	15	16	36.0	2000.0	80.*	6088.	1.9	1.7
117	17	16	24.0	200.0	80.*	2160.	1.5	0.2
118	16	18	24.0	2000.0	80.*	2402.	1.7	2.2
119	18	19	24.0	10.0	80.*	2402.	1.7	0.0
120	18	38	24.0	10.0	80.*	0.	0.0	0.0
122	12	15	24.0	10.0	80.*	6088.	4.3	0.1
123	13	15	24.0	10.0	80.*	0.	0.0	0.0
124	14	15	24.0	10.0	80.*	0.	0.0	0.0
130	16	30	24.0	20000.0	80.*	1929.	1.4	14.5
131	31	30	16.0	200.0	80.*	211.	0.3	0.0
134	30	34	16.0	10000.0	80.*	0.	0.0	0.0
139	39	41	24.0	10.0	80.*	2402.	1.7	0.0

PIPE NO.	NODES FROM	TO	DIAM. IN.	LENGTH FT.	COEF	FLOW GPM	VEL. FT/SEC	HEAD LOSS
140	40	41	24.0	10.0	80.*	0.	0.0	0.0
141	41	42	24.0	15000.0	80.*	2402.	1.7	16.3
143	42	43	24.0	200.0	80.*	846.	0.6	0.0
144	42	44	16.0	2000.0	80.*	0.	0.0	0.0
221	16	22	24.0	7000.0	80.*	691.	0.5	0.8
222	16	21	8.0	7000.0	80.*	110.	0.7	5.3
223	23	20	16.0	200.0	80.*	0	0.0	23.0
224	22	21	8.0	200.0	80.*	691.	4.4	4.6
225	22	20	24.0	5000.0	80.*	0	0.0	0.0
226	21	20	8.0	5000.0	80.*	411.	2.6	43.5
229	30	20	16.0	10000.0	80.*	1538.	2.5	34.3

```
ENTER NUMBER CORRESPONDING TO TIME STEP TO VIEW FLOWS AND PRESSURES FOR ENTIRE
SYSTEM (ENTER N FOR NO VIEWING, R TO RETRIEVE TABLE)
N

TIME SIMULATION MENU

SELECT PROGRAM OPTION:

     BEGIN SIMULATION     : ENTER 0, PRESS RETURN
     MODIFY,ENTER DATA    :       1
     PRINT TIME DATA      :       2
     STORE TIME DATA      :       3
     RETRIEVE TIME DATA   :       4
     PROGRAM CONTROL      :       8
     TERMINATE            :       9

9
```

Section 7. Error Messages in the WADISO Program

28-44. Messages. This section gives messages that the program displays when an error is detected. A description of each message is provided telling the user what to do.

Message	Description
ALLOCATED MEMORY CAPACITY EXCEEDED. TRY INCREASING MNL IN ALL THE PARAMETER STATEMENTS, OR RENUMBERING THE SYSTEM.	MNL, the second subscript on the N1 and N2 arrays, must be increased due the size of system. Renumbering the system so that the ranges of link and node numbers are relatively close together may also solve the problem. See Documentation (Part 2) for additional information.
ALLOCATED MEMORY CAPACITY EXCEEDED. TRY INCREASING PNL IN THE PARAMETER STATEMENTS.	Due to the size of the system, PNL, the subscript on all link and node arrays, will need to be increased. See Documentation (Part 2) for additional information.
BEGIN AND END OF RANGE NEEDED. ENTRY IGNORED.	The user did not enter the beginning and ending nodes when specifying which nodes are to be assigned to a usage pattern using the RANGE option with the SPATIAL keyword. Two values are required after RANGE.
BEGINNING MUST BE LESS THAN END.	The user entered a beginning node for the range of nodes assigned to a usage pattern that exceeds the ending node number entered. User must reenter the line, with the first number after RANGE lower than the second number.
BEGINNING OR ENDING NODE DOES NOT MATCH THIS PIPE.	A check valve was entered for a link, but the beginning or ending node did not match the link. Recheck the link to make sure beginning and ending nodes are right or that link has been entered.
BEGINNING TIME MUST BE LESS THAN ENDING.	The user has specified a range of time steps for which loading factors are to be entered. However, the third value on the line is less than the second so that the program cannot prompt the user for entries. Reenter line with second value less than third.

Message	Description
CANNOT RETRIEVE SYSTEM, TOO MANY LINKS. TO RETRIEVE, INCREASE LNL IN SOURCE CODE TO MAXIMUM NUMBER OF LINKS xxxx.	Program attempted to retrieve a file containing system data, but the file was stored under a different LNL (the maximum number of links permitted) value than the current value. The program can store data for only LNL links and nodes. To retrieve file, increase LNL in the parameter statements in the source code to xxxx and recompile the program.
CANNOT RETRIEVE SYSTEM, TOO MANY NODES. TO RETRIEVE, INCREASE LNL IN SOURCE CODE TO MAXIMUM NUMBER OF NODES xxxx.	Program attempted to retrieve a file containing system data, but the file was stored under a different LNL (the maximum number of links permitted) value than the current value. The program can store data for only LNL links and nodes. To retrieve file, increase LNL in the parameter statements in the source code to xxxx and recompile the program.
CHARACTERISTIC CURVE IS CONCAVE UP.	The coefficient of the quadratic term in the pump characteristic curve is positive. Reenter heads and discharges on the characteristic curve, or use a single point followed by an "E."
CHECK FOR PORTIONS OF SYSTEM DISCONNECTED FROM A TANK.	The program could not balance the system during an extended period simulation. Since the program was able to balance the system in the steady-state simulation, several tanks may be disconnected, pumps turned off, or pipes closed, preventing the program from balancing the system. Check the time simulation output for this time.
CORRECT FORMAT FOR KEYWORD (keyword) IS:	This message is displayed whenever user enters a keyword followed by no numerical values. The correct format for the keyword is displayed. Only the keyword NODE can be entered without numerical data.
DATA FOR NODE xx WAS NOT YET ENTERED.	User must specify at least an elevation for each node. Water input or a tank water level may also be specified.
DEFAULT ASSIGNED TO PATTERN 1.	The user did not assign any loading factors to water uses at nodes. The program will assign default factors to pattern 1. This is an information message.

Message	Description
DISCHARGES ARE TOO CLOSE TOGETHER.	When entering the discharges for the pump characteristic curve, points on the curve need to be spread out.
DIVISION BY ZERO WHILE SOLVING THE LINEARIZED EQUATIONS. CHECK AROUND NODE xx FOR POSSIBLE ERRORS.	The system could not be balanced. Check nodes and links around the node given.
ELEMENT yy WAS PREVIOUSLY ENTERED FROM xx1 TO xx2. NEW DATA RETAINED.	Link element yy was already entered from node xx1 to node xx2. The old data will be replaced by the new data.
ELEVATION MUST BE GREATER THAN OR EQUAL TO ZERO.	A negative elevation for a node was entered. Reenter the node elevation with a value greater than or equal to zero using keyword ELEV.
END OF EXCLUDING AT TIME xx WITH PIPE yyyy IS LATER THAN DURATION zz HOURS.	The time when a pipe reopens is later than the duration. This is a warning message. Note that xx is given in units of hours, not time steps.
END OF FIRE AT TIME xx AT NODE yyyy IS LATER THAN THE NUMBER OF STEPS zz.	The time step at which a fire is to end is greater than the total number of time steps. This is a warning message. The user should remember that the beginning of the fire and duration of fire are given in units of time steps, not hours.
END OF PUMPING AT TIME xx WITH PUMP yyyy IS LATER THAN DURATION zz HOURS.	The time when pumping is to end is greater than the duration. This is a warning message. Note that the beginning of pumping and duration of pumping are given in units of hours, not time steps.
ENDING TIME OF EXCLUDING IS EARLIER THAN BEGINNING TIME FOR PIPE yyyy.	The time when a pipe closes is later than when it opens. Reenter the open and close times for pipe yyyy with the closing time earlier than the opening time. Note that all pipes are assumed open at the beginning of the simulation unless the first closing time is 0 hours. Note also that time is in hours, not time steps.
ENDING TIME OF PUMPING IS EARLIER THAN BEGINNING TIME FOR PUMP yyyy.	The time when a pump turns off is earlier than when it turns on. Reenter the on and off times for pump yyyy with the on time earlier than the off time. Note that time is in units of hours, not time steps.

Message	Description
ERROR IN INPUT.	An error was made on the format for a keyword. Check the user's guide for a complete listing of keywords and their formats or type "KEYW" to receive a list of keywords, and then type the keyword to receive the correct format for the keyword.
EVERY ON TIME MUST HAVE AN OFF TIME. ENTRIES IGNORED.	When entering on and off times to control a pump, an on time did not have an off time. Renter the data, being sure to follow each on time by an off time.
FIVE FIRES ALREADY DEFINED/ DELETE ONE BEFORE ADDING ANOTHER.	Program can store data for only five fire nodes. Consider combining two fire nodes into one.
FOUR ENTRIES REQUIRED FOR FIRE NODE, START, DURATION AND FLOW.	User did not enter four numeric values on FIRE line. Reenter line with correct number of values.
xxxx HAS NOT BEEN ASSIGNED FOR PRINTING OR IS NOT A LINK.	User attempted to delete printing of flows through link xxxx during the extended period simulation. The link was never assigned for printing or xxxx is not a link. Recheck the link numbering in the system.
xxxx HAS NOT BEEN ASSIGNED FOR PRINTING OR IS NOT A NODE.	User attempted to delete printing of pressures (or tank water levels) at node xxxx during the extended period simulation. The node was never assigned for printing or xxxx is not a node. Recheck the node numbering in the system.
xxxx HAS NOT BEEN DEFINED AS NODE. ENTRY IGNORED.	Extended period simulation data for a tank at node xxxx has been entered but node xxxx does not exist. Enter that node in the steady-state simulation data (by making it the end node for a pipe or pump) before entering tank specifications with TANK keyword.
HAZEN-WILLIAMS COEFFICIENT IS TOO SMALL.	The Hazen-Williams coefficient must be greater than zero. Increase the coefficient using the keyword COEF.
ILLEGAL GROUP #.	Only group numbers from 0 through 15 inclusive are allowed. Adjust the group number so that it falls within this range.

Message	Description
ILLEGAL KEYWORD.	An invalid keyword was entered. Check the user's guide for a complete listing of keywords and their format or type "KEYW" to receive a list of valid keywords. Type the keyword followed by no numerical data to receive the correct format.
ILLEGAL LOAD PATTERN #.	Only five loading patterns (from 1 through 5 inclusive) may be specified.
ILLEGAL PIPE #.	This pipe does not exist in the system at present. Recheck the list of links entered.
ILLEGAL PRICE FCT. #.	Only price functions ranging from 0 through the number of price functions entered are allowed. Adjust the price function so that it falls within the range.
ILLEGAL SECOND KEYWORD.	An invalid second keyword was entered. Check the user's guide for correct format.
INITIAL LEVEL xx MUST BE BETWEEN UPPER yy AND LOWER zz LIMITS.	User has specified an initial water level that is outside the acceptable range of water levels. User must reenter initial water levels.
INSUFFICIENT DATA FOR KEYWORD.	The required number of numeric values following the keyword was not entered. The correct format(s) for the keyword is displayed following the message. Follow this format.
INVALID RESPONSE TO MENU.	The only numeric values recognized by the extended period simulation main menu are 0, 1, 2, 3, 4, 8 and 9.
xxxx IS A TANK ENTRY IGNORED.	Node xxxx has been entered as a tank in the steady-state simulation data. Fires can be specified only at nontank nodes. Assign fire to such a node. Similarly, this node cannot be assigned to a water use pattern.
xxxx IS INVALID KEYWORD. ENTRY IGNORED.	User has entered an invalid keyword. Check the manual or type "KEYW" to receive a list of valid keywords.
xxxx IS NOT A LINK. ENTRY IGNORED.	User attempted to exclude link xxxx from the system, but the link has not been defined in steady-state simulation. Other values on this line are not ignored.

Message	Description
xxxx IS NOT A PUMP. ENTRY IGNORED.	Data for pump xxxx were entered, but link xxxx is not a pump in the steady-state simulation. Enter data describing link xxxx as a pump in the steady-state simulation input.
xxxx IS NOT A TANK. ENTRY IGNORED.	Data for a tank at node xxxx have been entered, but node xxxx has not been declared a tank in the corresponding steady-state simulation. Enter data describing node xxxx as a tank in steady-state simulation input.
LINK NUMBER TOO LARGE.	A link number exceeding the maximum link number was entered. Link number should be decreased, if possible, or the parameter, PNL, in the program, may be increased. See Documentation (Part 2) for additional information.
LINK yy IS NOT A NOT A PIPE. LINK IS IGNORED.	Link yy is either a pump or PRV and is ignored for optimizing purposes.
MAXIMUM SIZES ARE INSUFFICIENT IN PATTERN X.	The minimum pressure in pattern X is less than the pressure tolerance.
MORE DATA ENTERED THAN REQUIRED FOR KEYWORD (keyword).	More numeric values than were needed followed the keyword. Check the user's guide for the correct format(s) and reenter data for the keyword.
MUST BE 2 OR 3 ENTRIES FOR USAGE. ENTRY IGNORED.	User must specify the usage pattern being entered and either the time step or range of time steps for which values are being entered. The user will be prompted for the actual loading factors on the following lines.
MUST SPECIFY NODE, UPPER AND LOWER LEVELS, AREA, AND OPTIONALLY, INITIAL ELEVATION.	The user did not enter the correct number of numeric values following the keyword TANK. Reenter the line with either four or five values to specify the tank for an extended period simulation or one value, the node number, to delete tank specifications.
NO GROUPS ASSIGNED !	The user attempted to optimize a system but has not yet assigned any groups. Select "MODIFY OPT. DATA" from the optimization menu and assign links to groups.

Message	Description
NO LINK WITH THIS NUMBER, OR LINK IS NOT A PUMP.	An attempt was made to include a link as a pump in determining the energy cost while optimizing. However, the link either does not exist or is not a pump. Recheck the system.
NO LOADING ASSIGNED !	The user attempted to optimize a system but has not yet assigned any loading patterns to the system. Select "MODIFY OPT. DATA" from the optimization menu and assign loading patterns to the system.
NO PIPE # yy.	The user attempted to include pipe yy in a group for optimization, but pipe yy is not in the system. Even if a pipe is not part of the existing system, it needs to be included in the system with some arbitrary diameter in the simulation portion of the program.
NO PRV OR CHECK VALVE CAN BE EXCLUDED.	The user attempted to exclude a pressure reducing valve or check valve from an extended period simulation. Only pipe links may be excluded. To work around this, exclude short pipe links on either side of the PRV or check valve.
NO SIZE FOR CLEANING IN COST TABLE.	A size for cleaning was specified which is not contained in the cost table. Add it to the cost table using keyword SIZE after selecting "MODIFY DATA" from the cost menu.
NO SIZE IN COST TABLE.	A size was specified for a new pipe, but this size does not exist in the cost table. All sizes must be included in the cost data file. Add the cost for that size to the cost table with the keyword SIZE after selecting "MODIFY DATA" from the cost menu.
NO SIZES ASSIGNED TO GROUP yy.	The user attempted to optimize a system but did not assign sizes to pipes in group yy. Select "MODIFY OPT. DATA" from the optimization menu and assign sizes to group yy.
NO SUCH NODE NUMBER.	A node number which is not part of the system followed a keyword. Recheck the node numbering in the system. Node must be indicated on PIPE or PUMP card before node data are entered.

Message	Description
NODE #, ON LEVEL, AND OFF LEVEL MUST FOLLOW SECOND KEYWORD.	User has entered keyword pump in the extended period simulation input followed either by the second keyword LEFT, or LEPSI. A node number controlling the pump, and off and on levels in feet or pounds per square inch, must follow the second keyword. Reenter the keywords with correct format.
NODE xxxx HAS NO PIPE LEADING TO IT. NODE IS IGNORED.	Node xxxx is not connected with the system and will be deleted. Check the system for a possible numbering error.
NODE xxxx IS A SUPPLY POINT.	Node xxxx has a fixed head. For optimization purposes, this node will not be compared with a minimum allowable pressure.
NODE xxxx IS NOT AN OUTPUT POINT.	While using keyword RATIO, node xxxx was included in the range but has no output, so no output can be multiplied by the factor; however, other nodes in the range will still be multiplied by the factor.
NODE xxxx NOT ASSIGNED TO USE PATTERN. USE PATTERN 1 WILL BE USED.	The user did not assign node xxxx to a use pattern. This is a warning message to indicate that node xxxx is being assigned to the default loading pattern 1. If this is acceptable to the user, no response is required. If this is the wrong loading, the user should change it with a SPATIAL entry assigning the node to another use pattern.
NODE xxxx NOT ASSIGNED TO USE PATTERN. USE PATTERN 1 WILL BE USED.	The user did not assign node xxxx to a use pattern. This is a warning message to indicate that node xxxx is being assigned to the default loading pattern 1. If this is acceptable to the user, no response is required. If this is the wrong loading, the user should change it with a SPATIAL entry assigning the node to another use pattern.
NODE NUMBER TOO LARGE.	A node number exceeding the maximum node number was entered. If possible, node number should be decreased. If not, the parameter PNL in the program may be increased. See Documentation (Part 2) for further details on when array dimensions need to be increased.

Message	Description
xxx NOT DEFINED AS NODE.	User attempted to assign node xxxx to a water use pattern, but the node is not part of the system. Check the node number. If it is valid, the user must return to steady-state simulation data input and enter a pipe or pump connected to this node.
xxxx NOT RECOGNIZED. ENTRY IGNORED.	The user has entered an invalid keyword. He should consult the user's guide or enter KEYWORD to receive a list of correct keywords.
NUMBER OF STEPS MUST BE AT LEAST ONE.	User attempted entering a number less than 1 with keyword STEPS. The number of time steps must be an integer greater than or equal to 1. Reenter the keyword STEPS followed by a valid entry.
OFF AND ON TANK LEVELS OF TANK xxxx CONTROLLING PUMP yyyy ARE NOT CONSISTENT WITH UPPER AND LOWER TANK LEVELS.	User has entered a tank water level controlling a pump that is greater than the maximum water level of the tank or smaller than the minimum water level of the tank. Reenter either the tank water levels controlling the pump or the maximum and minimum tank water levels.
ON LEVEL HIGHER THAN OFF LEVEL.	The user has specified either a tank water level or a pressure that turns on the pump which is greater than the tank water level or pressure that turns off the pump. Reenter the levels, specifying an on level that is smaller than the off level.
ONLY 1 VALUE CAN BE SPECIFIED WITH RATIO. ENTRY IGNORED.	The RATIO entry corrects all of the water uses by multiplying them by a constant. It cannot be applied to individual nodes. To change individual nodes, consider setting up a new usage pattern with the USAGE entry.
ONLY 10 ENTRIES CAN BE PRINTED. DELETE ONE BEFORE ADDING ANOTHER.	User attempted to display data for more than 10 nodes and links, but the program can only store up to 10 nodes and links. Either delete one of the existing nodes or links from being printed or run the extended period simulation again with different nodes and links assigned for printing on each run.

Message	Description
PIPE DIAMETER MUST BE GREATER THAN ZERO.	Only positive pipe diameters are allowed.
PIPE LENGTH RANGE IS FROM 0 to 1000000 FEET.	Pipe length must be greater than zero and less than 1,000,000 feet. Adjust the length using keyword LENG so that it falls within this range. If pipe length was entered using keyword PIPE, all other data associated with this keyword must be reentered.
PIPE yy DOES NOT HAVE A PARALLEL PIPE. CLEANING CANNOT BE SPECIFIED.	For cleaning purposes, all pipes in a group to be considered for cleaning must have pipes with different link numbers but the same beginning and ending nodes. The parallel pipes will be considered for cleaning and not sizing.
POSITIVE SHUTOFF HEAD REQUIRED.	A pump characteristic curve was entered resulting in a negative shutoff head. Enter new heads and discharges, or use a single set of values followed by an "E."
PRESSURE SETTING MUST BE GREATER THAN ZERO.	Only positive pressure settings are allowed. Reenter in keyword PRV. When the prompt for pressure setting is displayed, enter a positive value.
PRIOR TO OPTIMIZING, THIS SYSTEM MUST BE BALANCED.	Before optimizing, the system must be balanced with the simulation routine. If it is not balanced, the computer will automatically balance the system and display output.
PRIOR TO RUNNING AN EXTENDED PERIOD SIMULATION, THE SYSTEM MUST BE BALANCED.	The system must be balanced with the steady-state simulation routine before beginning the time simulation. If it is not balanced, the computer will automatically balance the system before beginning the time simulation.
PRIOR TO RUNNING AN EXTENDED PERIOD SIMULATION, TIME DATA MUST BE ENTERED.	The time simulation data must be entered before running the simulation. Select "MODIFY, ENTER DATA" option from the menu and input the time data.

Message	Description
PROGRAM CANNOT ACCESS THIS FILE.	When retrieving data, the file cannot be accessed because it either does not exist under the specified name or it is not a local file (if using the Cyber). Recheck the name of the file, and, if using the Cyber, be sure that it is a local file by using the CDC command GET, filename. This message is also displayed when storing data on the IBM PC and no more space exists on the diskette. If storing on a diskette, replace the diskette with one containing sufficient memory and try storing the data again.
PUMP CANNOT DELIVER DISCHARGE.	This warning message is displayed during balancing when a negative head difference is present and when the iteration counter is greater than 2. The head difference is adjusted to 5 percent of the pump head at a flow of zero. Pump is trying to deliver flow to the right of point at which head is zero. This message and following can occur when there is no constant head node upstream of pump. The head difference is set to a value between 80 percent and 100 percent of the pump head at a flow of zero, depending on the iteration.
PUMP CANNOT DELIVER HEAD.	When the head difference is greater than the pump head at a flow of zero and the iteration counter is larger than 2, this warning message is displayed. Pump is trying to deliver head greater than highest point on head characteristic curve.
PUMPS WITH UNSPECIFIED CHARACTERISTIC CURVES.	Pumps were sized while optimizing, and the user needs to assign new characteristic curves to them.
PUMP yyyy ALREADY HAS 7 ON/OFF TIMES DEFINED.	The user attempted assigning more than seven pairs of off and on times to a pump. The program can only store up to seven pairs of off and on times.
RATIO SET TO 1.	User did not enter a RATIO. Program will use the water use rates specified in the steady-state simulation input without any correction (i.e., RATIO = 1). This is an information message.

Message	Description
REPEAT OF DISCHARGE. START OVER.	At least two of the discharges entered for the pump characteristic curve were equal. Reenter discharges and heads using three different discharges, or use a single point followed on next line by "E."
SECOND KEYWORD MUST BE LEFT, LEPSI, OR TIME.	User has entered the keyword PUMP in the extended period simulation input to assign pump controls. However, the user did not indicate whether the pump is to be controlled by tank water level (LEFT), node pressure (LEPSI), or time step (TIME). Reenter the line with the keyword LEFT, LEPSI, or TIME.
SECOND KEYWORD MUST BE NODE OR RANGE.	User has entered the keyword SPATIAL to assign nodes to water use patterns, but the second keyword on the SPATIAL entry is not one of the valid entries of RANGE or NODES. Reenter the line with the keywords RANGE or NODES following the water use pattern number.
SECOND KEYWORD MUST BE ON OR OFF.	User entered the keyword BEGIN to initially turn pumps on or off, but the second keyword on the BEGIN entry is not one of the valid entries of ON or OFF. Reenter the line with the keywords ON or OFF following the pump number.
SECOND KEYWORD NEEDED.	User has entered the keyword SPATIAL to assign nodes to water use patterns. However, the user did not indicate whether a RANGE of nodes is specified or individual NODES are listed. User must specify RANGE or NODES after entering the use pattern number.
START OF EXCLUDING AT TIME xx WITH PIPE yyyy IS LATER THAN DURATION xx HOURS.	The user has specified that a pipe is to close at time xx, which occurs after the end of the extended period simulation. User can either close the pipe at an earlier time or increase the duration. Note that xx is in units of hours, not time steps.
START OF FIRE AT TIME xx AT NODE yyyy IS LATER THAN NUMBER OF TIME STEPS zz.	The user has specified that a fire is to begin at time step xx, which occurs after the end of the extended period simulation. User can either start the fire at an earlier time step or increase the number of time steps. Note that xx is in units of time steps, not hours.

Message	Description
START OF PUMPING AT TIME xx WITH PUMP yyyy IS LATER THAN DURATION zz HOURS.	The user has specified that a pump is to begin pumping at time xx, which occurs after the end of the extended period simulation. User can either start the pump running at an earlier time or increase the duration. Note that xx is in units of hours, not time steps.
SYSTEM DATA FOR STEADY STATE SIMULATION MUST BE ENTERED PRIOR TO THE TIME SIMULATION.	A time simulation cannot be run without first entering a system consisting of links, nodes, and supply points. Return to the steady-state simulation routine and enter the system data.
SYSTEM NOT BALANCED AT TIME STEP zzzz.	When running an extended period time simulation, the computer was unable to balance the system at time step zzzz. Flows and pressures at the time step are immediately displayed following the message.
TANK AT NODE xxxx MUST HAVE LIMITS AND AREA.	The system contains a tank at node xxxx, but the user did not specify the upper and lower water levels for the tank or the cross-sectional area of the tank. The user must enter these values or delete the tank from the steady-state simulation input. Extended period simulation will not run unless tanks have been properly specified.
TANK HEIGHT MUST BE GREATER THAN ZERO.	Only positive tank water levels are allowed. Enter keyword TANK followed by the node number and positive water elevation.
TANK xxxx IS A CONSTANT HEAD TANK.	The user specified zero as the cross-sectional area of the tank. The program is warning the user that it is assigning a very large area (1E10) to the tank so that the water level in the tank will not fluctuate from its initial level.
THE FOLLOWING COMBINATION FAILED BECAUSE OF PUMP zz.	While optimizing, this combination failed due to pump link zz. Inspect the pump curve.
THIS LINK IS NOT A PIPE.	This link was entered as a pump or PRV. Recheck the system.
THIS PIPE WAS NOT ENTERED.	Do not attempt to enter DIAM, LENG, or COEF until link has been entered on a PIPE or LINE card.

Message	Description
TOO MANY LINKS. INCREASE PNL IN SOURCE CODE TO MAXIMUM LINK NUMBER xxxx.	Program retrieved a file containing system data, but the file was stored under a different PNL value than the current PNL value. The program can only store up to PNL links and PNL nodes. To perform any operation on this system, increase PNL to xxxx in the parameter statements in the source code and recompile the program.
TOO MANY NODES. INCREASE PNL IN SOURCE CODE TO MAXIMUM NODE NUMBER xxxx.	Program retrieved a file containing system data, but the file was stored under a different PNL value than the current PNL value. The program can only store up to PNL links and PNL nodes. To perform any operation on this system, increase PNL to xxxx in the parameter statements in the source code and recompile the program.
TOO MANY VALUES PER LINE.	The user has indicated that more than 15 numeric values for loading factors will be specified on the following line. The program will accept only 15 at a time. Break the loading factors into lines with less than 15 values per line. Several USAGE entries will be required.
TWO ENTRIES REQUIRED WITH "TIME," NOT xxxx.	When using the second keyword TIME along with keyword PUMP in the extended period simulation, specify only the starting time step of pump running and the duration of pump running.
UPPER LIMIT xx FT OF TANK XXXX MUST BE LARGER THAN LOWER LIMIT yy FT.	User has a tank bottom elevation lower than the top water level. User must correct this entry before running extended period simulation.
USAGE PATTERN MUST BE BETWEEN 1 and 5.	The program can store only five usage patterns, numbered 1 through 5. User has specified value outside that range.
USE PATTERN MUST BE BETWEEN 1 and 5.	User attempted to assign a node to a use that was outside the range of 1 to 5. Nodes can only be assigned to use patterns 1 through 5.
USE PUMP KEYWORD TO EXCLUDE PUMP yyyy.	User attempted to exclude pump yyyy for a period of time from an extended period simulation using keyword EXCL. Keyword EXCL is only for pipes. Use keyword PUMP for pumps.

Message	Description
VALUE MUST BE IN COLUMN 1.	In responding to the main extended period simulation menu, the numeric value must begin in column 1. There must be no blanks or other characters before the numeric value.
xxxx VALUES USED.	The program prompted the user for a specific number of values for loading factors based on the data on the USAGE line. The user did not enter exactly that number of values. This indicates that xxxx values were accepted.
WARNING: CONVERGENCE DURING BALANCING MAY BE A PROBLEM DUE TO SHAPE OF CHARACTERISTIC CURVE.	Heads and discharges for a pump were entered resulting in a curve that can have two discharge values for one head. Although this is a valid curve, mathematically it may present some problems during balancing. If the system will not converge, change this pump curve.
xxxx WAS ENTERED AS A SUPPLY POINT. NEW DATA RETAINED.	Node xxxx was previously defined as a supply point, but it will be changed to an input or output node.
xxxx WAS ENTERED WITH OUTPUT/ INPUT. NEW DATA RETAINED.	Node xxxx was previously defined as a node having input or output. It is now defined as a constant head node.
xxxx WAS NOT DEFINED AS NODE. ENTRY IGNORED.	User specified a fire at node xxxx, but node xxxx is not connected to the system through a link (i.e., is not attached to pipe or pump). Correct the node number or enter a pipe or pump in the steady-state simulation connected to this node.
xxxx WAS NOT ORIGINALLY EXCLUDED.	User attempted to reinsert a pipe into the system which he had not previously removed. Other links described in this entry are reinserted.
YOU HAVE NO SUPPLY POINT.	At least one constant head node must be included in the system. Use the keyword TANK to enter water level at constant head nodes.
YOU MUST CHANGE PUMP.	A new characteristic pump curve that will deliver the required head and discharge must be entered for this pump, or this loading cannot be modeled.

Message	Description
ZERO ENTRIES IN LOADING xxxx.	The program found a time step in loading (usage) pattern xxxx which contains zero as an entry. This is simply a warning that the user may have forgotten to specify values for every time step for that loading. It is possible, however, that the user wishes to have zero flow for a given time step. In that case, this warning should be ignored.
15 PIPES ALREADY EXCLUDED. ENTRY IGNORED.	Program can store exclude data for only 15 pipes for an extended period simulation.
20 PUMPS ALREADY DEFINED. ENTRY IGNORED.	Only 20 pumps may be assigned controls for an extended period simulation.
20 TANKS ALREADY DEFINED. ENTRY IGNORED.	Program can store data for only 20 tanks for extended period simulation. If more than 20 tanks exist in the system, some must be deleted. A procedure for doing this is to combine two tanks that are close to one another into one node.

APPENDIX B

RUNNING THE WADISO PROGRAM ON CDC CYBERNET

B-1. Introduction. To run the WADISO program, the user must call the program from storage and start the program. This procedure varies from one computer to another, so it is not included in the user's guide. The procedure for the CDC Cybernet System is described below. Before the description of how to run the program on CDC, there is a short introduction on CDC computer file terminology and a description of the logon procedure.

B-2. Overview. After illustrating how to run the program for simple cases, subsequent paragraphs describe how to direct program output to a file, how to run the program in batch mode, and how to list, edit, and recompile the source program. Those familiar with the CDC Cybernet system can skip the sections on file terminology and logon-logoff procedure.

B-3. File Terminology. Before using the water distribution program, the user needs to understand the terminology for describing files. These terms are described below.

B-4. Program, Data, Output, and Batch Files. Several types of files are associated with the WADISO program. The files include the executable program; the program source listing; system data stored in the form of internal, interim, and external data files; output from previous program runs; and batch job files. Each type of file is described below.

a. Program Files. Program files are either executable or source. The WADISO program that is run by the user is an executable program file; the FORTRAN source listing, SWADISO, is a text program file. Executable files cannot be listed or modified by the user; however, text files can be examined and modified by the user with an editor.

b. External Data Files. This type of data file supplies responses to the program prompts and is used instead of entering data interactively. Anything that a user would enter interactively (e.g., keywords, data, menu responses, and internal data file names) is contained in the file. All prompts must be anticipated when creating an external data file. These files may be created with the CDC Cybernet editor, XEDIT, or uploaded from a microcomputer. An example involving a program run using an external data file is given in paragraph B-12. These files are needed when attempting to run WADISO as a batch job.

c. Internal Data Files. These files contain data that were entered by the user interactively or with an external data file. WADISO creates an internal data file when the user selects any of the STORE DATA options from the program menus. Internal data files are stored under a user-selected file name as formatted, sequential-access files opened on device 1. Four internal data files may be used. These may contain simulation, cost, optimization,

and extended period simulation data. These files may be viewed with an editor. A description of the formats and contents of the files is given in the program documentation (Part 2). Paragraphs B-8 through B-11 discuss interactive runs using internal data files.

d. Interim Data Files. Unlike internal data files, interim data files may contain simulation data from a partially entered system. They are used when a user cannot enter a complete system in one session. WADISO creates an interim data file when the keyword CREA is entered after the simulation keyword prompt is displayed. If a file name follows the keyword prompt, partial link and node data are stored under this file name; otherwise, data will be stored under the name SYSDA. Interim data files are formatted, sequential-access files and can be viewed by the user with an editor. Format and contents of the files are described in the documentation.

e. Output Data Files. These files contain output from a previous program run. Output data files enable the user to view a selective portion of the output with an editor. The user may also print a specific portion of the output. See paragraphs B-13 through B-15 on directing output to a file, examining output with an editor, and directing output to a RJE printer.

f. Batch Job Files. These files contain system commands that tell the computer what to do. Typically, batch files contain the sequence of commands to run an external data file with an executable program file and can save the user a considerable amount of money. An example involving a batch job file is given in paragraphs B-16 and B-17.

B-5. Permanent Versus Local. Files on the CDC Cybernet System can also be classified as permanent or local. Permanent files exist on disk at the site of the computer. In order to use these files, the user must make them local by issuing a GET command (e.g., GET,WADISO). Local files are lost when the user logs off the system. To save these files for future use, the user issues a SAVE or REPLACE command (e.g., REPLACE,MYFILE). The SAVE command can be used only if a permanent file with that name does not already exist.

B-6. Interactive Run. While the above sounds fairly complicated, for the simplest case, the user need only know that the binary program file is called WADISO and is a permanent file on account CECELB. To run the program, the user need only enter

```
/GET,WADISO/UN=CECELB
/WADISO
```

Of course, the user must have already logged onto the system. That procedure is explained below. (In the following sections, the slash mark at the start of each line represents the CDC System prompt. The user's responses are underlined.)

B-7. Logon/Logoff. For access to the Cybernet System, the user must obtain the telephone number from either the Cybernet sales representative for his area or the local Corps ADP coordinator. Once the user has dialed the Cybernet telephone number and the terminal is connected to the system, he receives the message

83/09/26/ 15.34.54.AA2451A
EASTERN CYBERNET CENTER SN487 NOS 1.4/531/.281/17AD
FAMILY: KOE

USER NAME:

to which he enters his assigned account number. For example, the user may enter

USER NAME: CEQQXX

He then receives the message

PASSWORD:

to which he enters his assigned password. For example, the user may enter

PASSWORD: PASSWD

He then receives the message

TERMINAL: 510, NAMIAF
RECOVER/CHARGE: CHARGE, ________ , ________

to which he enters his assigned charge number and project name. For example the user may enter

CHARGE,CHRGNO,ZZZZ

He then receives the message

$CHARGE,CHRGNO,ZZZZ/ /07.02.22./

The system responds with a slash mark, which indicates that the user is in the batch subsystem. Two question marks (??) indicate that the user is in the edit mode, and a single question mark (?) indicates that the user is in the input mode. If the user should make a mistake while logging on and the system prompts "APPLICATION:", the user should enter "IAF" for interactive facility. To logoff the system, the user types BYE in response to a / prompt. The computer responds by printing out some accounting information for the session before dropping the phone line.

B-8. Interactive Runs - No Existing Data File. The simplest way to run the WADISO program consists of the user making WADISO a local file using the GET command and then starting the program using the command WADISO.

/GET,WADISO/UN=CECELB
/WADISO

The first question asked by the program is

```
PROGRAM CONTROL:
     SIMULATION          :    ENTER 1 PRESS RETURN
     OPTIMIZATION        :          2
     COST DATA           :          3
     TIME SIMULATION     :          4
     TERMINATE PROGRAM   :          9
```

To enter a new system, the user must enter the simulation routine by answering with "1." The next prompt is

```
SELECT PROGRAM OPTION:
     TO ENTER NEW SYSTEM:  ENTER 1 PRESS RETURN
     TO RETRIEVE DATA:  2
```

In this case, the user must answer "1." The "2" response can only be issued if the user has a local, binary data file created during a previous run. To use the program as described above, the user must enter all the system data each time the program is run. This would quickly get tiring. The user can, however, store the data in a local, internal, data file by typing "3" in response to the simulation menu as described in the user's guide. The user is then asked to give a name to this file.

B-9. Saving File Created During Run. Suppose the user calls it "MYFILE." MYFILE is a local, internal data file and, because it is local, will be lost when the user logs off the system. To make the file permanent, the user must issue a SAVE or REPLACE command before logging off the computer. For example,

/SAVE,MYFILE

If the file MYFILE is already permanent, the command must be REPLACE instead of SAVE. The user can also save MYFILE under a different file name (say DATA1) by entering

/SAVE,MYFILE=DATA1

Once the file is saved, the user can logoff or rerun the program. If the user wishes to rerun the program using the data just entered, he need only enter

/WADISO

In response to the "SELECT PROGRAM OPTION" question, he should answer "2." The program will then ask for the local data file name, to which the user should respond

MYFILE

While only one file is required to store data for simulations, three files are needed to store all of the data for optimization. The first contains the simulation data needed to describe the system, the second contains cost data, and the third contains information on which pipes are to be optimized. Suppose the user creates these three files, called SIMDAT (Simulation Data), COSDAT (Cost Data), and OPTDAT (Optimization Data). These files can be made permanent after a run using the command

/SAVE,SIMDAT,COSDAT,OPTDAT

or

/SAVE,SIMDAT
/SAVE,COSDAT
/SAVE,OPTDAT

B-10. Interactive Runs - Existing Internal Data File. It is seldom possible to complete a pipe network analysis in one session at the computer. Eventually, the user must logoff the computer. When the user logs on again, he would like to begin where he left off and not have to reenter all of the data. This is possible, if before logging off the previous session he made his internal, local data file into a permanent file (call it MYFILE for this example). To run WADISO in this instance, the user must make the executable program file and internal data file local.

/GET,WADISO/UN=CECELB
/GET,MYFILE
/WADISO

If this is to be an optimization run and the user has three optimization files, he would enter

/GET,SIMDAT,COSDAT,OPTDAT
instead of /GET,MYFILE.

To the question "SELECT PROGRAM OPTION," the user would answer "2" and would then supply the internal data file name "MYFILE."

B-11. Replacing Existing Data Files. If the user wishes to save changes made to the data, during this run and subsequent runs, he must issue a STORE DATA (i.e., "3") in response to the main menu which makes changes to the local file, and must replace the local file using

/REPLACE,MYFILE

which makes the local, internal data file permanent. If the user wishes to save the data in MYFILE as originally created and save any changes in another file (say MYFILE2), the user would enter

/REPLACE,MYFILE=MYFILE2

In this case, there will be two permanent, internal data files: MYFILE containing the original data and MYFILE2 containing the updated data.

B-12. Interactive Runs - External Data File. Some users, especially those familiar with the CDC Cybernet Editor, may prefer to build data files using the editor and not bother with internal data files. (The CDC Cybernet Editor is called XEDIT.) This has some advantages in that the user can modify and list data without using the program, merge files to build large networks from small ones, and use the data files for batch runs later. The primary disadvantage is that the user must learn how to use the editor. Suppose the user wants to build a external data file (called TDATA) using the editor to run example problem 1 in the user's guide. The file, listed below, contains all of the information the user would enter in response to prompts during an interactive run. (Another disadvantage to using external data files is that the user must be able to anticipate all of the menus and prompts provided by the program.)

```
1 For first menu (Program Centres).  Simulation Data
1                                    New Data
EXAMPLE 1                            Job Card
101 2 3 12 2000
102 3 6 10 1500
111 12 13 12 5000
112 12 15 8 1500
114 15 16 8 1500
123 34 35 8 1500                     Pipe Data
124 35 36 8 1500
11 3 13 8 1800
13 6 16 10 1000
31 13 33 8 1000
32 25 35 8 1000
33 26 36 8 1000

PRV 22 15 25
60
23 16 26                             PRV Data
60

122 33 34
60
```

PUMP 110 11 12	
600 143	Pump Data
1000 130	
1400 111	
NODE	
950	
910	
905 50	
950	
970	
920	
890 80	
890 75	
890	Node Data
890	
870 50	
870	
870 75	
850 1500	
11 0	
2 100	
END	
0	Run Simulation
9	Stop Program

Values like 1, 0, and 9 are responses to various menus. When file TDATA is created, it will be local. The user may want to make it permanent with a /SAVE,TDATA command. To run the program, the user need only enter GET, WADISO and start the program.

/GET,WADISO/UN=CECELB
/WADISO,TDATA

If TDATA was not already local, the user would first need to make it local using

/GET,TDATA

The printout will contain all of the prompts and menus issued by the program. If the user receives an "END-OF-FILE" error message when attempting to start WADISO, he should REWIND,TDATA and rerun the program. If data are entered out of order, it is possible for the program to become stuck on a given menu. The user must correct the error before running the program.

B-13. Directing Output to a File. The user may not want to view all of the output from an run when an external data file is used, or he may wish to save output to a file (say TOUT). To do this the user enters

/GET,WADISO/UN=CECELB
/GET,TDATA
/WADISO,TDATA,TOUT

The program will respond with a message indicating how many CP seconds were used to run the program. The user can now make TOUT permanent if he wishes by entering

/SAVE,TOUT

He can list TOUT in its entirety by entering

/REWIND,TOUT
/LIST,F=TOUT

B-14. Examining Output with Editor. The user can use the editor to look at certain lines of output, or to skip all prompts and menus and print only the hydraulic output. To skip the menus the user enters

```
/XEDIT,TOUT
 EDIT MODE
 ??L/ACCUR/
 ACCURACY LIMITS  10 GPM; 2 PSI
 ??P  *
```
(Output will appear here)

B-15. Directing Output to RJE Printer. The output file can also be directed to a remote job entry (RJE) terminal printer by entering

/REWIND,TOUT
/ROUTE,TOUT,DC=PR,UN=account

where account is the user's account number.

B-16. Running Program Remote Batch - Existing External Data File. When the user is learning to use the program, entering data for a study, or analyzing a small system, the user can make the most of the program by running it interactively. For large networks, however, once the data files have been debugged, the user can save a considerable amount of money by running the program batch. To run the program batch, the user sets up a batch job file and submits it to the computer. The speed with which the computer works on the batch job depends on the priority assigned to the job by the user and the computer's workload. If the job has a priority of 5, it will be processed almost immediately after it is submitted at a cost roughly one half of interactive processing. If it is submitted with a priority of 2, it will usually be processed

overnight at one twentieth the cost of interactive processing. The savings using batch job processing can be quite significant. A typical batch job file (called BATCH) is shown below.

```
XEDIT,BATCH
Edit Mode
??(Hit Return)
Input
?/JOB
?EXAMPLE,P5.
?/USER
?/CHARGE
?GET,WADISO.
?GET,TDATA.                  Getting Files

?WADISO,TDATA,TOUT.          Running Program

?REPLACE,TOUT.
?DAYFILE,DAYF.               Saving Output and Dayfile
?REPLACE,DAYF.

?EXIT.
?DAYFILE,DAYF.               Saving Output and Dayfile if Error
?REPLACE,DAYF.
?REPLACE,TOUT.
?/EOR
?(Hit return)
??END,BATCH,SAVE
```

The JOB, USER, and CHARGE statements indicate that the batch job is to be charged to the same account as the user logged onto the system. The "EXAMPLE,P5" card assigns the job a name and a priority (5). If P2 was used, the job would have a priority of 2. The next several commands are similar to those for running WADISO from an external data file. TDATA and TOUT were described earlier. The DAYFILE commands save some job accounting information and system error messages.

B-17. Submitting Batch Job. To submit the batch job, the user enters

/SUBMIT,BATCH

The batch job commands do not need to be in the file called BATCH. Any file name can be assigned to that file (e.g., SUBMIT,BFILE). When the user submits the job, the computer will respond with a job number (e.g., ACF2JGG). The user can check on the status of the job using the "ENQUIRE" command and the last three digits of the job number. For example,

/ENQUIRE,JN=JGG

If the system responds "JOB NOT FOUND," the job is complete. The user can then GET the output file and, if needed, the dayfile by entering

/GET,TOUT,DAYF

The user can look at these files using the LIST command or the editor, as described earlier.

B-18. Deleting Files. Since output files are fairly large, permanent files and hence costly to store, they should be deleted after they have been listed. This can be done using the PURGE command as

/PURGE,TOUT

B-19. Listing Source Version. Occasionally, a user may want to obtain a listing of the text source file of the program. This file is called SWADISO and is stored under another account number. The user generally does not have permission to access this file. To obtain READ ONLY access, the user should call the program developers (601-634-3931). They will give the user access to the program and tell the user the account number under which it is stored. The user can then make the file local by entering

/GET,SWADISO/UN=account

where account is the account number under which the program is stored. The user can then save PIPNET under his account by entering

/SAVE,SWADISO

The user can use the editor to examine or modify the program or list the entire program by entering

/LIST,F=SWADISO

B-20. Compiling the Program. Users are discouraged from modifying the program. However, if they need to modify the program, they must edit their own copy of the text program file (SWADISO or some other name if they have changed the program name), recompile the program (i.e., make a new, executable program file), and save that file. To recompile the file, the user must make the text program file local and invoke the FORTRAN V compiler.

/GET,PIPNET
/FTN5,I=PIPNET,L=LIST,B=progname

This command creates a local binary program file called whatever name is used for "progname" (say WADISO2). The user can then make this version permanent on his own account by entering

/SAVE,WADISO2

To use this version of the program, the user enters

/GET,WADISO2

instead of

/GET,WADISO/UN=CECELB

as described in earlier sections. The file LIST (see FTN5 command above) is a local text file that contains a listing of the program plus compiler diagnostic messages. If the user only wants to see error messages, he should substitute L=0 for L=LIST in the FTN5 statement. If there are errors in the compilation and the user wishes to try again, he should rewind all files before reissuing the FTN5 command. For example,

/REWIND,PIPNET,LIST,WADISO2

B-21. Recovering a Lost Connection. During a run of the program, the terminal may be accidentally disconnected from the system, or a system malfunction may require that the login process be restarted, or the terminal may be logged off by the system after 10 minutes of inactivity. The user then has 20 minutes to recover the connection by restarting the login process and following the sequence to the point where the system requests

RECOVER/CHARGE:

The user now enters

RECOVER/CHARGE: RECOVER,xxx

where xxx is the terminal number being used when the broken connection occurred. In the example logon shown earlier, the terminal number is 510. This number may be found in the initial login sequence immediately before the request for USER ID in the form TERMINAL: xxx, NAMIAF or by executing ENQUIRE. The system should then respond

RECOVERY COMPLETE
LAST COMMAND - command
NEXT OPERATION

The user should then hit a carriage return and proceed from the point where the broken connection occurred. If an error message is received, the user has either allowed the 20-minute recovery period to elapse or has used an incorrect terminal number. He should then check the number and repeat the process. Sometimes recovery is not possible.

APPENDIX C

RUNNING THE WADISO PROGRAM ON THE IBM PC

C-1. Introduction. This appendix describes the required software and hardware to run the WADISO program, using the program with data files, directing program output to the printer, copying the program, listing the program, and compiling the program on the IBM PC.

C-2. Hardware. To run the microcomputer version of WADISO, an IBM PC or compatible computer with memory of 512K and an 8087 math coprocessor are needed. Recommended is a printer.

C-3. Software. The program disk contains the executable file WADISO.EXE, the external data files WADEXM and TIMEXM, and a batch file (EXAMPLE.BAT) to run the external data files. The source disk contains a listing of the WADISO program, WADISO.FOR.

C-4. Program, Data and Output Files. Several types of files are associated with the WADISO program. The files contain the executable program; the program source listing; system data stored in the form of external, internal, and interim data files; and output from previous program runs. Each type of file is described below.

a. Program Files. Program files are either executable or source. The WADISO program, WADISO.EXE, which is run by the user, is an executable program file; the FORTRAN source listing, WADISO.FOR, is a text program file. Executable files cannot be listed or modified by the user; however, text files can be examined and modified by the user with an editor.

b. External Data Files. This type of data file supplies responses to the program prompts and is used instead of entering data interactively. Anything a user would enter interactively (e.g., keywords, data, menu responses, and internal data file names) is contained on the file. All prompts must be anticipated when creating an external data file. These files may be created with EDLIN or the IBM Professional Editor or downloaded from a mainframe computer. Running WADISO with external data files is described in paragraph C-6.

c. Internal Data Files. These files contain data that have been entered by the user interactively or with an external data file. WADISO creates an internal data file when the user selects any of the "STORE DATA" options from the program menus. The program stores internal data files under a user-selected file name as formatted, sequential-access files opened on device 1. Four internal data files may be used. These may contain simulation, cost, optimization, and extended period simulation data. These files may be viewed with an editor. A description of the formats and contents of the files is given in the program documentation (Part 2). Paragraph C-7 discusses interactive runs using internal data files. Paragraphs 28-17, 28-28, and 28-40 of the User's Guide (Part 1) describe storing and retrieving internal data files.

d. Interim Data Files. Unlike internal data files, interim data files may contain simulation data from a partially entered system. They are used when a user cannot enter a complete system in one session. WADISO creates an interim data file when the keyword CREA is entered after the simulation keyword prompt is displayed. If a file name follows the keyword prompt, partial link and node data are stored under this file name; otherwise, data will be stored under the name "SYSDA." Data will be stored on the default drive. Interim data files are formatted, sequential-access files and can be viewed by the user with an editor. Format and contents of the files are described in the Documentation.

e. Output Data Files. These files contain output from a previous program run. Output data files enable the user to view a selective portion of the output with an editor. The user may also print a specific portion of the output. See paragraphs C-8 and C-9 on directing output to a file and to the printer.

C-5. Interactive Runs - No Data Files. After turning on the power, insert the program disk in drive A. Be sure the caps lock is on since WADISO will accept only uppercase letters. At this point the program can be run interactively by typing:

A>WADISO

(THE A> is the DOS prompt and user's response is underlined.)

or, if the default drive is C, type

C>A:WADISO

WADISO displays the main program menu and prompts the user for a response as described in the User's Guide, Chapter 28.

C-6. Batch Runs - External Data Files. To run the program with an external data file, enter

A>WADISO<fname

where "fname" is the name of a previously created text file providing responses to the program prompts.

C-7. Interactive Runs - Internal Data Files. After entering system data interactively, it may be stored by choosing the "STORE DATA" option from the appropriate menu. Internal data files created by WADISO will be stored on the default disk drive under the user-selected file name unless they are preceded by a drive specification other than the default drive. For example, assume drive C is the default drive and the STORE DATA option is selected from one of the menus in the program. The following prompt appears:

ENTER FILE NAME

_

At this point, the user may enter the name of the file, and the data will be stored on disk drive C under the selected name. Also, in response to the prompt, the user may type

A:datfile

at which point WADISO stores the data on the disk in drive A as "datfile."

Prior to storing any data, always check the disk to see there is adequate space to store the data.

To retrieve an internal data file from a drive other than the default drive, the drive specification must be given. Assuming the default drive is C and the data file, datfile, is located on drive A, the user types

A:datfile

in response to the file name prompt in WADISO after choosing the "RETRIEVE DATA" option.

In addition, these files are formatted and can be viewed with an editor such as EDLIN, sent to the printer or, for small systems, listed directly upon the screen. The contents of the file and their format are described in the program documentation.

C-8. Directing Output to a File. To direct the output of the program to a file to view a selective portion of the output, enter

A>WADISO>fname

Where fname is name of a file on which the output of the program will be stored on the default disk drive. Another drive may be specified as follows:

A>WADISO>C:fname

In this case, assuming drive A is the default drive, the output of the program will be stored on drive C as fname. Directing output in this manner may be most useful and easiest when running WADISO with external data files since no prompts are displayed. In this case, enter:

A>WADISO<fname1 >fname2

Where fname1 is the name of the text data file located on the default drive (in this case A) and fname2 is the name of the file on which the program run will be stored on the default disk drive.

C-9. Directing Output to the Printer. Several methods are available for directing output of the program to the printer. To direct output to both the screen and printer, press the Ctrl and PrtSc keys at the same time. Continuous printing is provided. Pressing the shift and PrtSc key, print what is on the screen. This method may be useful if only selective portions of the

output are desired. In addition, output from running WADISO with a external data file can be sent to the printer (without listing on the screen) by typing

A>WADISO<fname>PRN

Where fname is the name of an external data file located on the disk in drive A.

C-10. Deleting Data Files. To remove a data file from the disk, use the DOS commands of ERASE or DEL, as follows:

A>ERASE fname

assuming A is the drive containing the data file, fname. When deleting files, always be sure to specify the correct drive, filename, and directory.

C-11. Copying the Program to Another Drive or Directory. If the user has a fixed disk, he may wish to copy the program from the floppy disk to the fixed disk. To do this, enter

A>COPY WADISO.EXE C:

or, if the default drive is C, type

C>COPY A:WADISO.EXE C:

and the computer will copy the executable program code on to the fixed disk.

To copy the program into a specific directory on the fixed disk, type

A>COPY WADISO.EXE C:/dirname

where dirname is the name of the directory on which WADISO.EXE is to be placed. Other files on the floppy disk may also be copied to the fixed disk by substituting their name for WADISO.EXE.

WADISO now can be run from the C drive, interactively, or with a external data file. If WADISO.EXE and an external data file are on different disk drives, the user may run WADISO with the external file by typing

C>WADISO<A:fname

where WADISO.EXE is on the default drive, C, and fname is the name of a external data file on drive A.

C-12. Listing Source Version. To view the source code, WADISO.FOR, on the screen, use an editor or word processing package. For a printed copy, send the WADISO source code file to the printer by entering

A>TYPE WADISO.FOR > PRN

where WADISO.FOR is the name of the file located on drive A containing the source code.

C-13. Compiling the Program. If the user has modified the program, it must be recompiled and relinked before it can be run. The source code was compiled using IBM Professional FORTRAN, PROFORT, version 1.0 with the I option. Refer to the IBM Personal Computer Professional FORTRAN installation and use manual for complete details on compiling and linking.

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CHAPTER 28

WATER DISTRIBUTION SYSTEM ANALYSIS AND OPTIMIZATION

Section 1. Program Control

28-1. Introduction. The WADISO (Water Distribution System Analysis and Optimization) computer program is a program to assist the user in the selection of pipe sizes when designing or sizing water distribution systems. WADISO is written in ANSI Standard FORTRAN 77 and has been developed for both a CDC Cyber 175 and an IBM PC or compatible computer.

28-2. Overview. To supplement the comments provided throughout the source code, a description of the program execution is given in Sections 2 through 5. Section 2 describes execution of simulation routines, Section 3 describes cost routines, Section 4 documents optimization routines, and Section 5 documents extended period simulation routines. In addition, Section 6 provides brief descriptions for all subroutines and includes figures showing the hierarchy of subroutines in the program, gives definitions of variables, and describes when to modify array dimensions in WADISO to allocate additional memory to handle very large systems or make the program run on computers with limited memory.

Section 2. Simulation

28-3. Introduction. When the user selects SIMULATION (ST(1:1)='1', where ST is the character string containing the user's input) from the main program menu, WADISO calls subroutine SIMULA. SIMULA initializes variables, prompts the user to enter a new system or retrieve a previously entered set of system data, displays the simulation menu, and calls other simulation routines. Figure 28-1 shows a general flowchart of the simulation routine, and paragraphs 28-4 through 28-11 describe execution of each of the menu options.

28-4. Input. Entering of the system data is accomplished with subroutine INPDAT. SIMULA calls INPDAT when the user decides to enter data for a new system or to modify data of a current system. INPDAT supplies the simulation keyword prompt, reads in the input string (ST), decomposes the input string, and assigns numeric values in accordance with the keyword.

a. Prompt. The prompt contains the present keyword, KTYPE. KTYPE is initially set to the keyword JOB. After the job name is entered it is assigned to the variable JOB, and KTYPE is set to PIPE. KTYPE is updated by entering a new keyword as part of the response to the prompt. If no keyword is entered, KTYPE is retained from the previous entry.

b. Decomposing the Input String. If the input string starts with an alpha character, the first four characters (or characters to the first blank, whichever is less) of the word are accepted as the keyword and assigned to the variable KTYPE. If the input string starts with a numeric value, the keyword remains unchanged. Alpha data other than the keyword are ignored. Data items can be separated by blanks or commas. Numeric values in the input string are

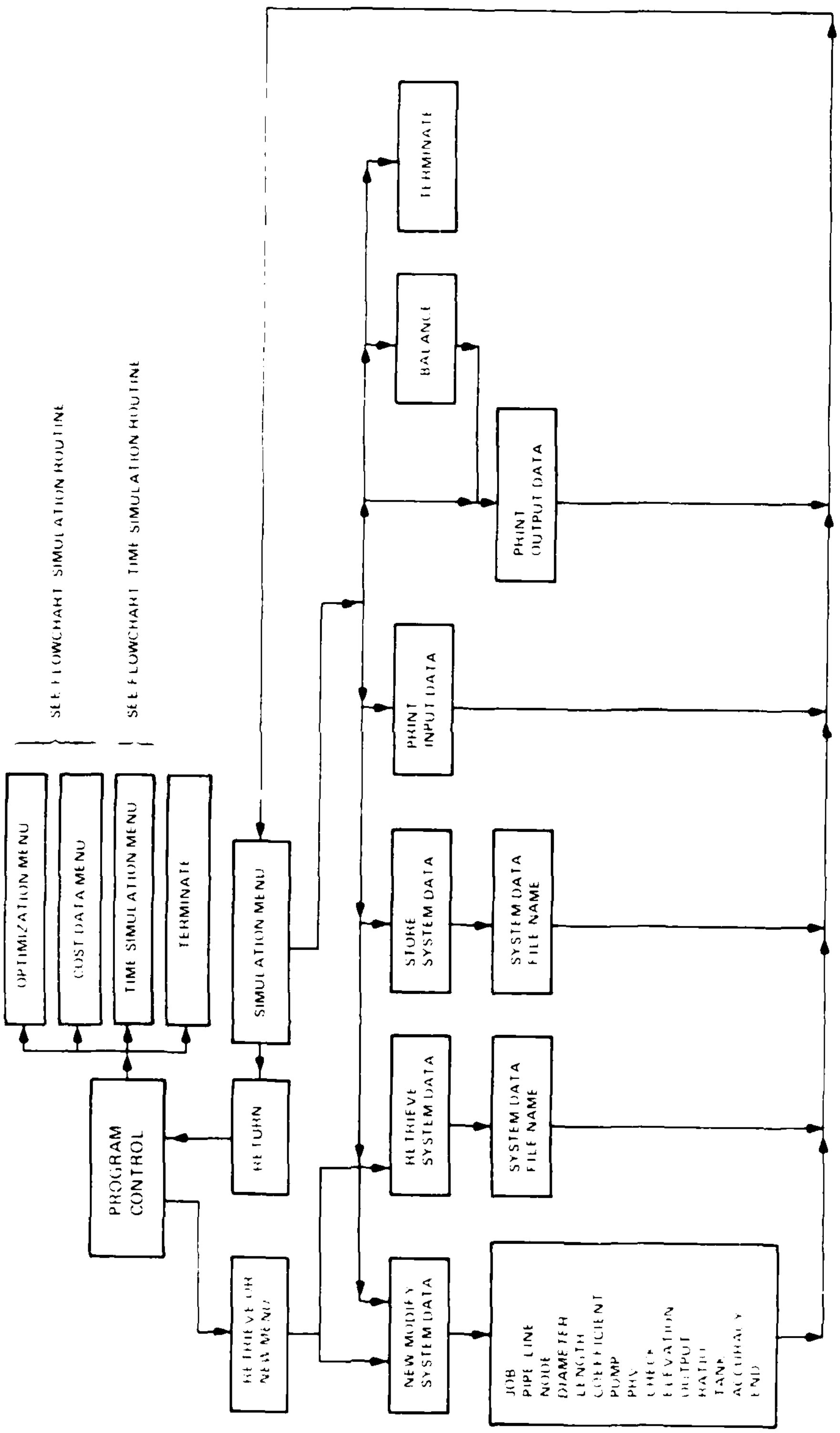


Figure 28-1. Flowchart, simulation routine

stored in the array VALUE, and L-1 represents the number of numeric values in the input string. In Table 28-1, an example of an input string and its decomposition is provided.

c. Recognizing Keyword. Program execution, within subroutine INPDAT, is transferred to the portion of the routine dealing with the present keyword based on the position of the keyword KTYPE in the strings KEY1, KEY2, and KEY3. These strings contain a list of all available keywords. The value L (number of numeric values plus one) is used, as well, in these tests.

d. Assignments of Numeric Values. Once the keyword has been determined, the numeric values in the input string, stored in array VALUE, are assigned to variables. For instance, if the keyword is "LENG," VALUE(2) (pipe length) is assigned to variable XL, subscripted with VALUE(1) (user link number). After making these assignments, control returns to the input prompt. Figure 28-2 provides a flowchart of system data input and retrieval, showing all the simulation keywords.

e. Errors in Data Input. If KTYPE is an invalid keyword, subroutine ERROR is called to display INVALID KEYWORD and set KTYPE to PIPE. INPDAT tests numeric values to verify that the correct format for the keyword was used and that each value is reasonable (e.g., no negative pipe diameter). If any error in the values is encountered, subroutine ERROR is called to display the appropriate error messages. Subroutine ERROR is also called to display correct format(s) for a keyword entered with no numerical values.

f. Links, Pumps, Check Valves, and Tanks. When any link data are entered or changed, INPDAT updates the characteristic pipe coefficient array (CP) and the matrix coefficient array (A) for the link. INPDAT stores the user link number in array IPI. To distinguish between pump links and pipe links, pumps are flagged with a negative characteristic pipe coefficient. The value assigned to CP for pumps is the coefficient of the quadratic term in the characteristic pump curve equation (a negative value). To distinguish check valve and PRV links from pipe and pump links, INPDAT flags check valves with a negative pipe length and PRVs with pipe lengths greater than 999999. A value of 100 is added to water levels in tanks to permit water levels of zero, and the levels are multiplied by 1E10 to distinguish tank nodes from other nodes; i.e., (DO = water level + 100) * (1E10).

g. Keywords CREA and GET. Two keywords, CREA and GET, transfer control from subroutine INPDAT to the subroutines SIMSTO and SIMRET, respectively. SIMSTO stores the simulation data on a formatted, sequential-access file opened on device 1 under the file name provided by the user. If no file name is specified, SYSDA is used. SIMRET retrieves the simulation data from the file created by SIMSTO. In the first line and first row of file SYSDA, 00 is stored. Following on line 1 are elements 1 through 14 of the O array, stored with a 14I4 format. Line 2 contains O(15), O1, and O2 with a 3I4 format. Afterwards, SIMSTO stores elements 1 through O2 of the node data arrays HE, DO, and EL using a 3E21.14 format specification. Next, SIMSTO stores elements 1 through O1 of the link data arrays A, CP, and DI using the same format specification. The routine stores the two remaining link data arrays

Table 28-1. Decomposition of User Input String

Input string: PIPE 20 170 175 10 200.5

String position	Character		
1	P	)	
2	I	)	First blank is in position 5
3	P	)	ST(1:4) is keyword
4	E	)	
5			
6	2	)	VALUE(1)=20
7	0	)	
8			
9	1	)	
10	7	)	VALUE(2)=170
11	0	)	
12			
13	1	)	
14	7	)	VALUE(3)=175
15	5	)	
16			
17	1	)	VALUE(4)=10
18	0	)	
19			
20	2	)	
21	0	)	
22	0	)	VALUE(5)=200.5
23	.	)	
24	5	)	

When decomposition of the input string is finished:
L = 6 (number of numeric values plus one)
KTYPE = PIPE

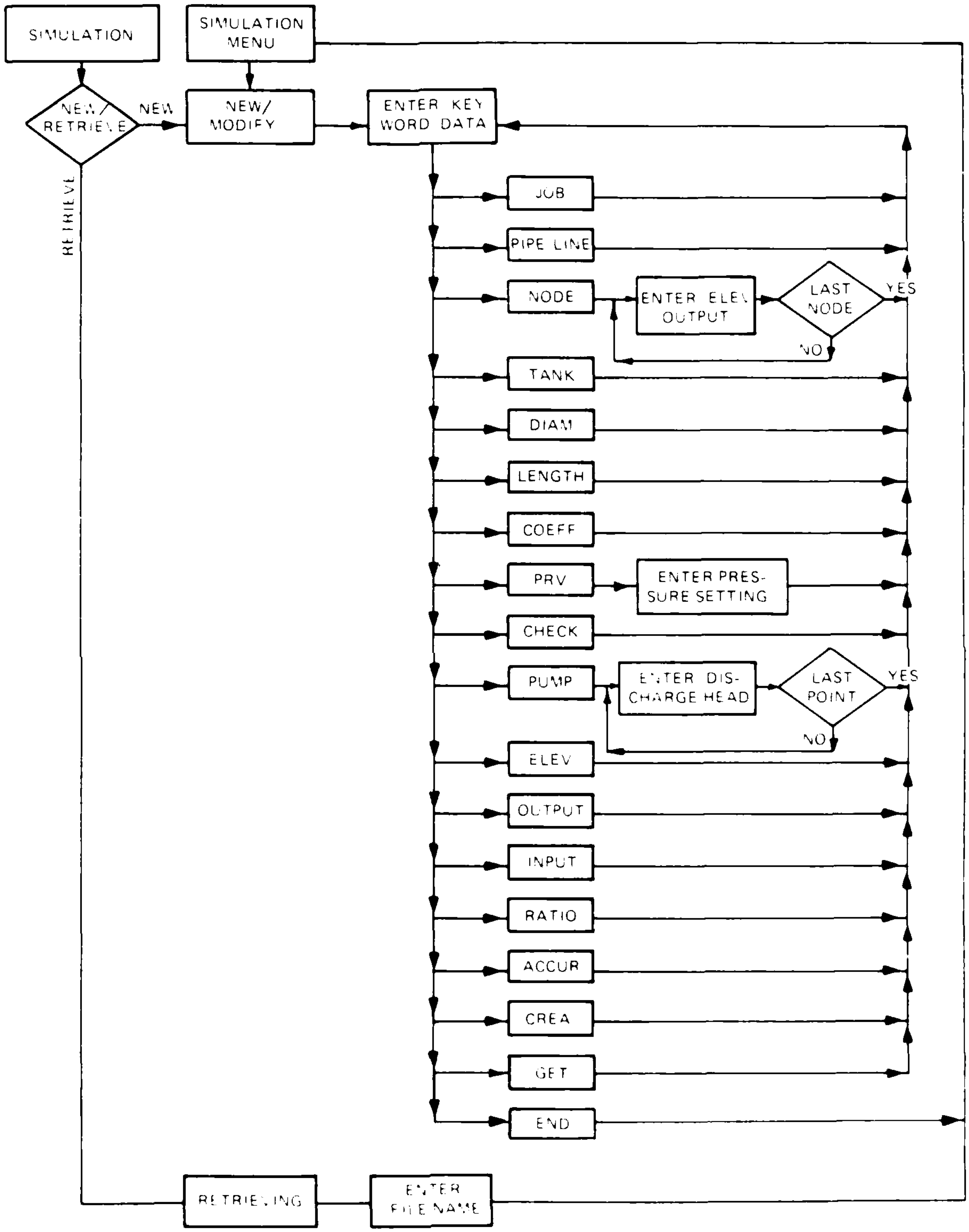


Figure 28-2. Flowchart, system data input and retrieval

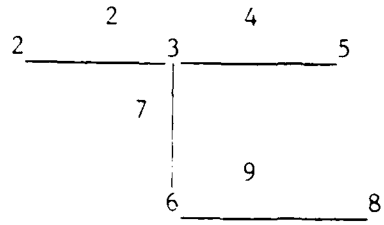
XL and HW (elements 1 through 01) using a 2E21.14 format specification. Following is the JOB name (A60 format) occupying one line and elements 1 through 02 of the arrays IBE, IEN, IPI, and INO with a 4I4 format specification. After retrieving or storing, return is made to the input prompt in subroutine INPDAT.

h. Keyword END. When the keyword END has been entered, the input data are processed. Checks are made to verify that every node has been assigned an elevation, every node has a pipe leading to it, and at least one node is a supply point (i.e., constant head node). Link data are compressed by shifting elements in arrays IPI, IBE, IEN, A, CP, DI, XL, and HW subscripted with the user link number to those arrays subscripted with internal link numbers. However, this assignment is made only when the elements in array IPI are equal to 1, to flag that a link does exist with that user number in the system. Node data are compressed in the same manner, by shifting the elements of the INO, HE, EL, and DO subscripted with user node numbers to elements of these arrays subscripted with internal node numbers. Arrays IPI and INO keep track of the shift. Figure 28-3 shows an example of a small system before and after compressing takes place. Expansion of the system data takes place with subroutine MODIFY, called by SIMULA prior to calling subroutine INPDAT, when the "MODIFY SYSTEM" (ST(1:1)='1') option is chosen. INPDAT returns program control to the calling subroutine, SIMULA, where the simulation menu is displayed.

28-5. Balancing. When BALANCE (ST(1:1)='0' or ST(1:2)='0C') is chosen from the menu, subroutine SIMBAL is called to create characteristics of the sparse matrix with two double-subscripted arrays, N1 and N2, in which the first subscript refers to the line number of the node in the matrix (internal node number) and the second subscript refers to the entry number of nonzero coefficients for each link connected to the node on this particular line (or zero coefficients that are needed during the Gaussian elimination procedure). Array M, subscripted with the line number, stores the number of entries used on this particular line in the sparse matrix excluding the entry on the diagonal (i.e., the highest second subscript in arrays N1 and N2 for a nonzero entry). Array N1 stores the internal link number (used when calling on the proper member in array A) and array N2 stores the column number in the sparse matrix in which the corresponding nonzero coefficient is located. This procedure allows the program to store the coefficient matrix in the one-dimensional array A. Establishing the sparse matrix is executed in two steps. In step 1, all the user-defined links are entered in the arrays N1 and N2. In step 2, the zero entries in the coefficient matrix, which are needed during the Gaussian elimination procedure (dummy links), are created. Below, an example is given showing a small network, the matrix, the arrays N1 and N2, and M after the first as well as the second step.

a. Example of Internal Node Numbering. Figure 28-4 shows the (internal) node numbers (to the lower right of the 0 marking the nodes) and link numbers (centered along the link). Note that if a system is numbered consecutively starting with 1, the internal and user numbers coincide. Figure 28-5 shows the corresponding coefficient matrix, marking with X the nonzero entries (* for the entry on the diagonal). Zero entries are left blank. Below the X,

System Layout:



Before compressing:

LINK #	1	2	3	4	5	6	7	8	9	(User Link #)
IPI		1		1			1		1	(Flag)
IBE		2		3			3		6	(User Beg. Node #)
IEN		3		5			6		8	(User End. Node #)

NODE #	1	2	3	4	5	6	7	8	9	(User Node #)
INO		1	1		1	1		1		(Flag)

After compressing:

LINK #	1	2	3	4	(Internal #)
IPI	2	4	7	9	(User Link #)
IBE	2	3	3	6	(User Beg. Node #)
IEN	3	5	6	8	(User End. Node #)

NODE #	1	2	3	4	5	(Internal Node #)
INO	2	3	5	6	8	(User Node #)

Figure 28-3. Example system before and after compressing data

```
       1         2          3        4         5
O--------O--------O--------O--------O--------O
1        |2       4        |5       |8        11
         |                 |        |
      10 |              11 |     12 |
         |                 |        |
         |        6        |        |    7
         O-----------------O        O--------O
         3                 |6       |        |12
                           |        |        |
                        13 |     14 |     15 |
                           |        |        |
                           O--------O--------O
                           7        10       13
```

Figure 28-4. System layout with internal node and pipe numbers

the internal link number is listed. Since the matrix is symmetrical, only the upper triangle is shown. At the far right, the number of nonzero entries (excluding the diagonal entry) is listed (value of M). Below the matrix, the corresponding arrays N1 (link numbers) and N2 (column/node numbers), as well as M, are shown after step 1. Figure 28-6 shows the matrix again. Here, the zero entries, indicated by # (dummy links) as needed during the Gaussian elimination procedure, have been added, with the corresponding "link" number as assigned by the program. Comments in the source code provide additional description of these steps.

b. Solution of Equations. After completing steps 1 and 2, SIMBAL calls EQSOLV to solve the O(2) (number of nodes in the system) continuity equations simultaneously for the unknown hydraulic heads, calculates the new coefficient matrix based on estimated flow rates calculated from the new heads, and repeats these two steps until the desired pressure and flow accuracy are reached. If the accuracies are yet insufficient, EQSOLV continues the iterative procedure. When solving the equations, EQSOLV operates only on the upper right triangle of the matrix, since it is always symmetrical. Overrelaxation of the hydraulic heads is provided only when no PRVs or check valves exist in the system, if the sum of all absolute head corrections (R3) is less than 75 percent of the sum in the previous iteration (C4), and if the iteration counter I6 is larger than 2 and less than or equal to 10. Once the desired flow (FLAC) and pressure accuracy (PRAC) are reached or the maximum number of iterations (ICL) is exceeded, program control transfers to subroutine PRNOUT, which prints the output. Flow and pressure accuracy are reached when the maximum absolute change in flow through a link between the previous iteration and the current iteration is less than or equal to FLAC and when the maximum absolute change in head at a node between the previous iteration and the current iteration is less than or equal to PRAC.

Node #	1	2	3	4	5	6	7	8	9	10	11	12	13	M
1	*	X 1												1
2		*	X 10	X 2										2
3			*			X 6								1
4				*	X 3									1
5					*	X 11		X 4						2
6						*	X 12							1
7							*			X 8				1
8								*	X 12		X 5			2
9									*	X 14		X 7		2
10										*			X 9	1
11											*			0
12												*	X 15	1
13													*	0

	Array N1				Array N2				Array M
	1	2	3	4	1	2	3	4	
1	1				2				1
2	10	2			3	4			2
3	6				6				1
4	3				5				1
5	11	4			6	8			2
6	12				7				1
7	8				10				1
8	12	5			9	11			2
9	14	7			10	12			2
10	9				13				1
11									0
12	12				13				1
13									0

Figure 28-5. Nonzero entries in the coefficient matrix with corresponding arrays N1, N2, and M

Node #	1	2	3	4	5	6	7	8	9	10	11	12	13	M
1	*	X												1
		1												
2		*	X	X										2
			10	2										
3			*	#		X								1
				16		6								
4				*	X	#								1
					3	17								
5					*	X		X						2
						11		4						
6						*	X	#						1
							12	18						
7							*	#		X				1
								19		8				
8								*	X	#	X			2
									12	20	5			
9									*	X	#	X		2
										14	21	7		
10										*	#	#	X	1
											22	23	9	
11											*	#	#	0
												28	25	
12												*	X	1
													15	
13													*	0

Array N1

	1	2	3	4
1	1			
2	10	2		
3	16	6		
4	3	17		
5	11	4		
6	13	18		
7	19	8		
8	12	20	5	
9	14	21	7	
10	22	23	9	
11	28	25		
12	12			
13				

Array N2

1	2	3	4
2			
3	4		
4	6		
5	6		
6	8		
7	8		
8	10		
9	10	11	
10	11	12	
11	12	13	
12	13		
13			

Array M

1
2
2
2
2
2
2
3
3
3
2
1
0

Figure 28-6. Entries in coefficient matrix with corresponding arrays N1, N2, and M as used during Gaussian elimination procedure

28-6. Printing Input. Selection of the option PRINT INPUT (ST(1:1)='2') transfers program control to subroutine PRNINP. PRNINP prints a node and link table and, if pumps are present, the coefficients of the characteristic curve follow the link table. PRNINP tests array DO, the water use at each node, for supply points. When DO is greater than 9E9, array HE (the total hydraulic head) and array EL (the node elevation) are compared. When HE is greater than EL by more than 0.5 foot for a node, the node is labeled as a tank. Otherwise, it is labeled as a reservoir. Checks are also made for the presence of PRVs (XL > 999999) or pumps (CP < 0) and check valves (XL < 0). After printing, return is made to subroutine SIMULA.

28-7. Printing Output. PRNOUT prints a node and pipe table displaying the output of the simulation listed by nodes and links. Subroutines NOTAHE and PITAHE print headings for the tables. SIMULA calls PRNOUT when the PRINT OUTPUT option (ST(1:1)='6') is chosen after a system has been balanced. Also, EQSOLV calls PRNOUT after balancing a system in the steady-state simulation routine. Following the printing, return is made to subroutine SIMULA.

28-8. Storing Data. When the option STORE DATA (ST(1:1)='3') is chosen from the simulation menu, SIMULA calls STODAT. After prompting for a file name, STODAT stores link and node data under this file name as a formatted, sequential access file opened on device 1. Line 1 of the file contains the entire O array, elements 1 through 15 with a 15I4 format. After storing this array, STODAT stores elements of the HE, DO, and EL arrays with a 3E21.14 format specification, taking up as many rows as there are nodes (O(2)). Next, the link data are stored, occupying as many rows as there are links. The routine stores arrays A, CP, and DI using a 3E21.14 format and then stores elements of the arrays XL and HW, using a 2E21.14. Following storing of the link data, STODAT stores the job name and then the arrays (IBE, IEN, IBI, IEI, and IPI), using a 5I4 specification. Lastly, the array INO is stored with a 10I4 specification. Figure 28-7 shows a formatted file created with STODAT from example 3 in the User's Guide (Part 1). Following storage of data, program execution returns to SIMULA, where the simulation menu is displayed.

28-9. Retrieving Data. If option RETRIEVE DATA (ST(1:1)='4') is chosen, control passes to subroutine RETDAT to retrieve the system data that were previously stored with subroutine STODAT on a formatted file opened on device 1. (Contents of the file and its format are discussed in paragraph 28-8.) After retrieving data, program control returns to subroutine SIMULA.

28-10. Program Control. The PROGRAM CONTROL (ST(1:1)='8') option returns control to the main program WADISO, where the main program menu is displayed.

28-11. Termination. When choosing TERMINATE PROGRAM (ST(1:1='9'), subroutine TERMIN is called to remind the user to transfer any local files to permanent storage (when working on the CDC Cybernet System) and terminate the program.

```
  11  10  0   0   0     0   0   0   0   0     0   0   0   0   0       0 ARRAY
0.10000000000000E+04   0.99999999590400E+12   0.10000000000000E+04
0.80000000000000E+03   0.10000000000000E+03   0.80000000000000E+03
0.80000000000000E+03   0.20000000000000E+03   0.80000000000000E+03
0.80000000000000E+03   0.00000000000000E+00   0.80000000000000E+03
0.78000000000000E+03   0.30000000000000E+03   0.78000000000000E+03   HE,DO,EL
0.80000000000000E+03   0.00000000000000E+00  -0.80000000000000E+03
0.78000000000000E+03   0.20000000000000E+02   0.78000000000000E+03
0.80000000000000E+03   0.00000000000000E+00  -0.80000000000000E+03
0.98000000000000E+03   0.30000000000000E+03   0.98000000000000E+03
0.95000000000000E+03   0.50000000000000E+03   0.95000000000000E+03
0.40817447814524E+00   0.24499328136444E+01   0.13333333730698E+01
0.42604446904692E+00   0.23471727371216E+01   0.11666666269302E+01
0.27916424742561E-01   0.35821205139160E+02   0.66666668653488E+00   A,CP,DI
0.42604446904692E+00   0.23471727371216E+01   0.11666666269302E+01
0.27916424742561E-01   0.35821205139160E+02   0.66666668653488E+00
0.10908329584911E+04  -0.31476129531860E+02  -0.16959516797215E-02
0.27916424742561E-01   0.35821205139160E+02   0.66666668653488E+00
0.27916424742561E-01   0.35821205139160E+02   0.66666668653488E+00
0.27916424742561E-01   0.35821205139160E+02   0.66666668653488E+00
0.68771437354017E-02   0.14540921020508E+03   0.50000000000000E+00
0.27916424742561E-01   0.35821205139160E+02   0.66666668653488E+00
0.10560000000000E+05  -0.10000000000000E+03
0.52800000000000E+04  -0.10000000000000E+03
0.52800000000000E+04  -0.10000000000000E+03
0.52800000000000E+04  -0.10000000000000E+03
0.52800000000000E+04  -0.10000000000000E+03
0.00000000000000E+00   0.40000201416016E+03                          XL,HW
0.52800000000000E+04  -0.10000000000000E+03
0.52800000000000E+04  -0.10000000000000E+03
0.52800000000000E+04  -0.10000000000000E+03
0.52800000000000E+04  -0.10000000000000E+03
0.52800000000000E+04  -0.10000000000000E+03

EXAMPLE 3                                                            JOB
  11     21     1    2      11
  21     31     2    4      21
  22     32     3    5      22
  31     41     4    6      31
  32     42     5    7      32                                       IBE,IEN,
  41     51     6    8      41                                       IBI,IEI,
  51     61     8    9      51                                       IPI
  61     71     9   10      61
  21     22     2    3     121
  31     32     4    5     131
  41     42     6    7     141
  11     21    22   31      32    41    42    51    61    71         INO ARRAY
```

Figure 28-7. Formatted file created with subroutine STODAT

Section 3. Cost

28-12. Introduction. When the COST option (ST(1:1)='2') is chosen from the main program menu, WADISO calls subroutine COSTDA, the calling routine for all cost routines. Subroutine OPTIMI may also call COSTDA when the user selects the cost option from the optimization menu. Default cost data are described in paragraph 28-13, while each of the size cost options displayed in the cost menu is described in paragraphs 28-14 through 28-19.

28-13. Default Cost Data. Default cost data are assigned in block data ASSIGN. ASSIGN puts 25 pipe sizes (inches) in array SIZ with their costs (dollars per linear foot) in array COST. Cost is a doubly subscripted array (first subscript refers to the size number, while the second refers to the price function) so that more than one price function can be used. Initially, two price functions are contained in array COST. Price function 1 contains the default values for pipe cost, and function 2 contains the default values for the cleaning cost. The default energy cost, ENCO, is $0.1 per kilowatt-hour; the number of years, NY, is 10 (used in the computation of present worth of pumping cost); and the interest rate is 0.1 (10 percent).

28-14. Input. When entering new cost data, COSTDA calls subroutine INPCST to display the cost input prompt and read in the keyword(s) and numeric values. To decompose the input string (ST), INPCST calls subroutine DECINP to separate the input string into keyword(s) and numeric values. Primary keywords (the first of two keywords when two keywords are entered) are stored under KTYPE, and secondary ones (the second keyword entered) under KTYPF. Numeric values are stored in the array VALUE. After decomposing the input string in DECINP, INPCST determines which keyword was entered. If an invalid keyword was entered, INPCST displays a warning message, sets KTYPE to SIZE, and control returns to the input prompt. The values associated with the keyword are stored under the appropriate variable names. If no numeric values follow the keyword, subroutine KEYWRD is called to display the correct format(s) for the keyword. INPCST also calls KEYWRD when KEYW is entered. Program execution goes back to the cost input prompt, and the process is repeated until the keyword END has been entered, at which point transfer is made to subroutine COSTDA where the cost menu is displayed showing six options for the user.

28-15. Printing Data. When PRINT DATA (ST(1:1)='2') is chosen from the cost menu, COSTDA calls subroutine PRNCST to display the pipe sizes in inches and their costs in dollars per linear foot for each of the price functions. Also, the cost printing routine displays the energy cost, ENCO; the time period, NY, used in the computation of present worth of pumping cost; and the interest rate, XI.

28-16. Storing Data. STORE DATA option (ST(1:1)='3') passes program control to subroutine STOCST where the user is prompted to enter a file name on which the data will be stored. STOCST opens the formatted, sequential access file on device 1 and stores on line 1 the number of sizes (KS) and the number of price functions (KC) using a 2I3 format specification. The pipe sizes in inches, found in array SIZ, and their corresponding costs in dollars per linear foot, assigned to the doubly subscripted array COST, are stored next

with a format specification of 6E12.5, so that six values are located on a line (three sizes, each followed by its cost). On the last line of the file, STOCST stores the energy cost (dollars per kilowatt-hour), the number of years, and the interest rate with a E12.5,I3,E12.5 format. Figure 28-8 shows an example of a formatted file created with STOCST using cost data taken from example 3 in the User's Guide. After storing the cost data, control returns to subroutine COSTDA, where the cost menu is displayed.

28-17. Retrieving Data. Selection of RETRIEVE COST DATA (ST(1:1)='4') transfers control to subroutine RETCST. RETCST prompts the user for the name of a file on which the cost data have been stored using subroutine STOCST and proceeds to open the file on device 1 and read the contents. If the file does not exist or is not accessible, RETDAT notifies the user with a message. See paragraph 28-16 for a description of the contents and format of the file.

28-18. Program Control. See paragraph 28-10.

28-19. Termination. See paragraph 28-11.

KS KC 25 2 Sizes, in. SIZ array	Prices, $/l.f. Function 1 COST array	Function 2 COST array	Sizes, in SIZ array	Prices, $/l.f. Function 1 COST array	Function 2 COST array
0.20000E+01	0.62900E+01	0.30000E+02	0.30000E+01	0.85700E+01	0.30000E+02
0.40000E+01	0.10800E+02	0.30000E+02	0.60000E+01	0.15100E+02	0.14500E+02
0.80000E+01	0.19300E+02	0.15700E+02	0.10000E+02	0.28900E+02	0.16800E+02
0.12000E+02	0.40500E+02	0.17700E+02	0.14000E+02	0.52100E+02	0.18500E+02
0.16000E+02	0.59400E+02	0.19200E+02	0.18000E+02	0.68600E+02	0.20000E+02
0.20000E+02	0.80100E+02	0.20500E+02	0.24000E+02	0.10600E+03	0.21600E+02
0.30000E+02	0.14700E+03	0.23100E+02	0.36000E+02	0.19200E+03	0.24300E+02
0.42000E+02	0.24200E+03	0.25400E+02	0.48000E+02	0.29500E+03	0.26400E+02
0.54000E+02	0.33100E+03	0.00000E+00	0.60000E+02	0.39600E+03	0.00000E+00
0.66000E+02	0.47700E+03	0.00000E+00	0.72000E+02	0.55400E+03	0.00000E+00
0.78000E+02	0.64200E+03	0.00000E+00	0.84000E+02	0.73400E+03	0.00000E+00
0.96000E+02	0.94±00E+03	0.00000E+00	0.10800E+03	0.11700E+04	0.00000E+00
0.12000E+03	0.14200E+04	0.00000E+00			
0.75000E-01	10 0.1000E+00	(Energy Cost ($/kwh), # of years, interest rate)			

Figure 28-8. Formatted file created with subroutine STOCST

Section 4. Optimization

28-20. Introduction. When OPTIMIZATION is chosen from the main program menu, WADISO calls subroutine OPTIMI, which displays the optimization menu and passes control to another subroutine based on the user's selection. Description of each of the menu options is given in paragraphs 28-21 through 28-26; Figure 28-9 shows a general flowchart for optimization routines.

28-21. Data Input. When MODIFY OPT. DATA (ST(1:1)='1') is chosen from the optimization menu, subroutine OPTIMI calls subroutine OPTMOD. OPTMOD displays the optimization input prompt, reads in the user's input as string ST, calls subroutine DECINP to decompose the input string into keyword(s) and numeric values, and makes assignments of the numeric values associated with the key-words to the appropriate variables. For keywords HWCC, LIMP, and LIMC, this assignment is straightforward, but for keywords GROU, LOAD, PRIC, and SIZE, some additional explanation is needed.

a. Keyword GROU. In dealing with the keyword GROU, the variable IGROU is used to assign links to a group. The subscript in array IGROU is the internal link number, and assigned to IGROU is the number of the group to which the link belongs. For example, if the user enters

```
GROU 1 1 4 6
     2 2 3
     3 5
```

the program would contain

```
IGROU  1   2   3   4    5   6   (subscript) - link
       1   2   2   1    3   1   (value) - group
```

Links with internal numbers of 1, 4, and 6 belong to group one. Links 2 and 3 belong to group 2, and link 5 belongs to group 3. Since there can be only 15 groups, the validity of the group number, which must be between 0 (0 is used to delete pipes from a group) and 15 inclusive, is tested. A test is also made to ensure that nonpipe links, such as PRVs and pumps, are not assigned to groups. If an illegal group number is entered, the entry is ignored; if a link is entered which is not a pipe, the link is not assigned to a group.

b. Keyword LOAD. With keyword LOAD, the presence of a second keyword must also be tested. Possible second keywords are MINI, RATI, OUTPUT, and PUMP. The table below shows the number of numeric values that may follow each keyword.

Second Keyword	Number of Numeric Values Following
MINI	1, 2, or 3
RATI	1 or 3
OUTPUT	2
PUMP	3

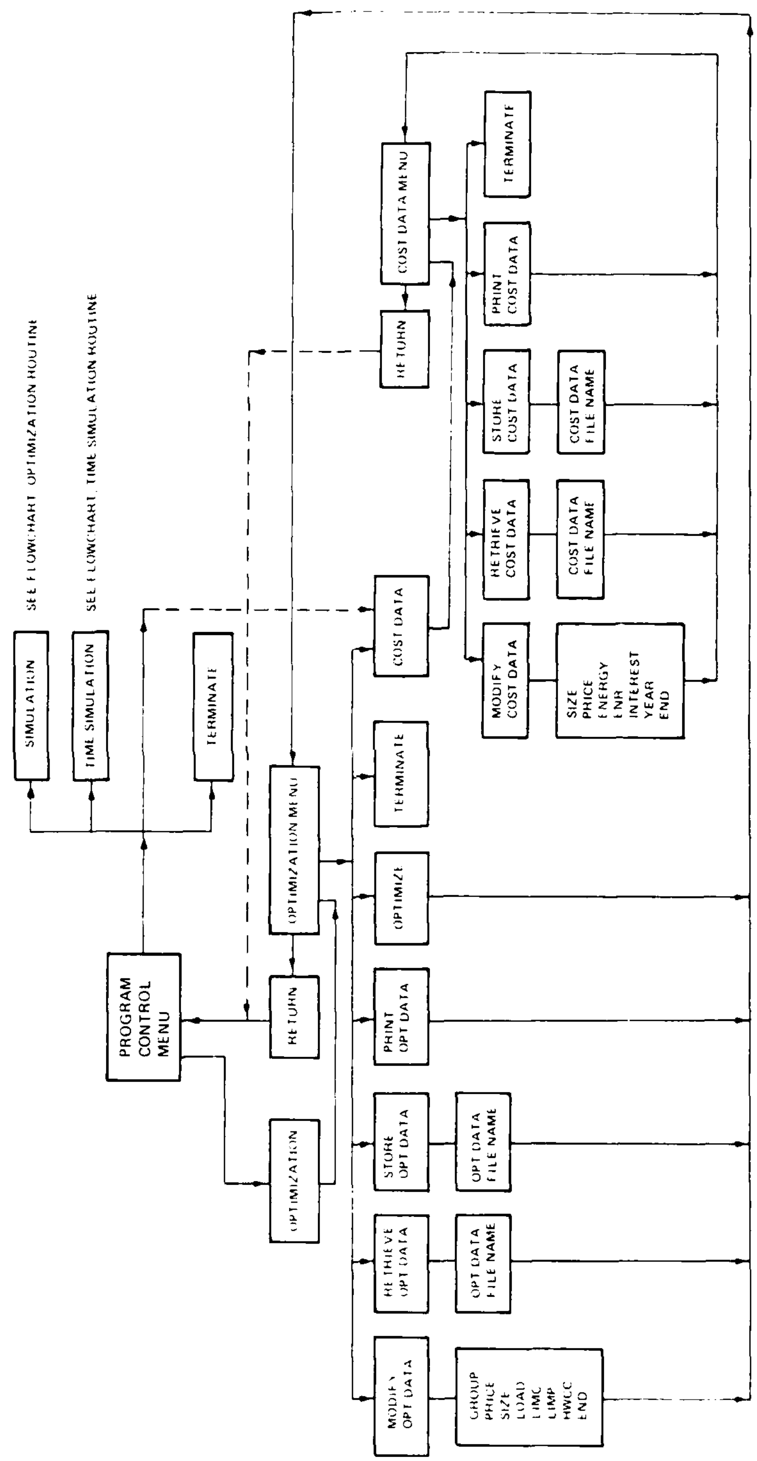


Figure 28-9. Flowchart, optimization routine

OPTMOD must determine how many values follow the second keyword so that assignment can be made over the appropriate range of nodes. OPTMOD also checks to ensure the node numbers entered by the user exist and that the loading pattern is in the range of 1 through 5 inclusive. If either error has been made, an error message is displayed, and control returns to the input prompt.

(1) One numeric value following. If only one numeric value follows the second keyword, the lower node bound (variable K0) for which output will be changed or pressure requirement made is assigned to 1, the number of the first internal node. The upper node bound (variable K1) is assigned to the total number of nodes, O(2). For example, if the user enters "LOAD 1 MINI 50," all nodes, except constant head nodes, would be assigned a minimum pressure of 50 pounds per square inch under loading pattern 1.

(2) Two numeric values following. If two numeric values follow the second keyword, the lower bound and the upper bound are identical since assignment is to be made for only one node. For example, if the user enters "LOAD 1 OUTPUT 12 500," K0 and K1 are assigned to the internal node number which corresponds to the user node number of 12 (stored in array INO), and an output of 500 gallons per minute is assigned to the node. If a constant head node is assigned the load, OPTMOD displays a message notifying the user that the node is a supply point but that output data are retained. After assignments have been made, return is made to the input prompt.

(3) Three numeric values following. If three numeric values follow the second keyword, the first value after the second keyword, value (2), is assigned to the lower bound; the second value is assigned to the upper bound; and the last value is the numerical value of the ratio or pressure requirement. For example, if the user enters "LOAD 1 RATIO 25 53 1.25," K0 is assigned to the internal node number matching the user node number of 25, and K1 is assigned to the internal node number matching user node number 53. Outputs in the range of external node numbers between 25 and 53 are multiplied by 1.25.

c. Keyword PRIC. If the keyword PRIC is entered, pipes are assigned to a price function with the array ICATE. As with IGROU, the internal link number is the subscript on the array, and the price function is assigned to the array. For example, in response to the optimization keyword prompt, the user enters

```
PRICE 1 1 3 4 6
      2 2 5
      3 7
```

Assuming consecutively numbered links beginning with link 1, so that external and internal link numbers are the same, the data are stored as follows.

ICATE	1	2	3	4	5	6	7	(subscript) - link number
	1	2	1	1	2	1	3	(assignment) - price function

Pipes with internal link numbers 1, 3, 4, and 6 are assigned to price function 1 (i.e., the cost of pipes 1, 3, 4, and 6 will be calculated based on price function 1). Pipes with internal link numbers of 2 and 5 are assigned to price function 2, and the pipe with internal link number 7 is assigned to price function 3.

d. Keyword SIZE. For keyword SIZE, new sizes are added to array NS and stored in the doubly subscripted array SI. The first subscript denotes the group number; the second denotes the number of sizes in the group, NS. If the list of sizes contains the letter C for cleaning/lining, the size counter is incremented by 1 and a value of -1 is assigned to the next element in array SI. For example, if the user enters "SIZE 2 8 10 12 C," the data are stored as follows:

SI (2,1) = 8
SI (2,2) = 10
SI (2,3) = 12
SI (2,4) = -1

28-22. Optimization. When OPTIMIZE (ST(1:1)='0') is chosen from the optimization menu, OPTIMI calls subroutine OPTRUN. To optimize the system, OPTRUN calls on subroutines OPTINT, ENUMER, and OPTERM, which in turn call several other routines. Execution is described below.

a. Subroutine OPTINT. This subroutine performs three major operations. OPTINT accumulates pipe cost for each size specified in each group (e.g., the costs for all 12-inch pipes in group 1 are added), performs a test on size range, and initializes a queue of nonfunctional combinations.

(1) Cost accumulation. Total costs for each size in each group are contained in array TC. The array has two subscripts, with the first referring to the group number and the second referring to the number of the size in the group. Sizes in each group are contained in array SI, which is subscripted in the same manner as array TC. After initializing array TC to zero, OPTINT tests the array SI for sizes in a group which the user has specified for elimination (i.e., a size of zero for a group has been specified). In this case, no cost is accumulated, and the size counter is increased by 1. A check for cleaning is also made; in this case, the user has specified a "C" as one of the sizes in a group, and the program flags cleaning by storing a "-1" in array SI in subroutine OPTMOD. When cleaning has been specified for a size, OPTINT checks for a parallel pipe (i.e., one with a different link number but the same beginning and ending node numbers). If no parallel pipe is found, an error message is displayed, and program control returns to the optimization menu. Otherwise, OPTINT calculates the diameter that would have to be assigned to the new pipe such that the old pipe (with the old Hazen-Williams coefficient) and the new pipe with this diameter are equivalent to the cleaned/lined old pipe alone. This diameter is

$$\text{DECL} = \left[\frac{\text{HWCC - HW(IP)}}{\text{HW(IL)}}\right]^{0.38} * \text{DI(IP)} \qquad (28\text{-}1)$$

where

HWCC = Hazen-Williams coefficient of cleaned pipe
HW = Hazen-Williams coefficient for pipes IL and IP
IP = internal link number of old pipe
IL = internal link number of new pipe
DI = diameter

Next, OPTINT searches the cost table for the diameter of the old pipe with internal link number IP. If no cost for a given size is found, a warning message is displayed, and program control returns to the optimization menu. Otherwise, cleaning cost for the size is accumulated by multiplying the length of the pipe (array XL) by the cost (array COST in dollars per linear foot) and adding the cost to array TC. For the case of neither elimination nor cleaning, OPTINT searches for the size in the cost table. If the size is not found, a warning message is displayed, and program control returns to the optimization menu. Otherwise, OPTINT determines the price of the pipe that is contained in array ICATE and subscripted with the internal link number IL. Once the price function is determined, the costs of each length in the group are summed, and OPTINT continues with the next pipe in the group with the same diameter as the previous pipe. If there are no more pipes in the group, the size counter is incremented. Once all the costs for all sizes in a group have been determined, the group counter is incremented. After accumulating cost for each size in each group, OPTINT sorts arrays TC and SI by cost from the most expensive to the least expensive size in each group. Next, duplicate sizes and sizes that are more expensive than the next larger size are eliminated. The following example will help illustrate the procedure. Group 1 contains pipes 22, 32, 121, and 141. Each pipe is 5,280 feet long. Pipe sizes assigned to this group are 10, 6, 8, and 4 inches, and the sizes were assigned in this order. The array SI then has these entries

SI(1,1)=10 SI(1,2)=6 SI(1,3)=8 SI(1,4)=4

given the following unit prices:

Size	Cost/foot
4	17.2
6	15.1
8	19.3
10	28.9

After accumulating cost, the array TC has the following entries:

TC(1,1)=610368 TC(1,2)=318912 TC(1,3)=407616 TC(1,4)=363264

After sorting:

SI(1,1)=10	SI(1,2)=8	SI(1,3)=4	SI(1,4)=6
TC(1,1)=610368	TC(1,2)=407616	TC(1,3)=363264	TC(1,4)=318912

After elimination:

SI(1,1)=10	SI(1,2)=8	SI(1,3)=6
TC(1,1)=610368	TC(1,2)=407616	TC(1,3)=318912

(2) Test on size range. After accumulating cost, sorting, and eliminating, OPTINT tests whether some small sizes in each group can be ruled out. Initially, all groups are assigned the maximum size by setting array ICS, subscripted with the group number, to 1 (i.e., the largest size corresponds to a size number of 1). OPTINT calls on subroutine SIZE to assign pipe diameters to array DI and characteristic pipe coefficients to array CP in accordance with the size number stored in array ICS. After returning from subroutine SIZE, the program enumerates each loading pattern and assigns water uses to array DO for the particular pattern. OPTINT calls OPTBAL, which in turn calls EQSOLV to calculate the pressure distribution. EQSOLV returns with the lowest pressure P8 (actual pressure minus required pressure) at any node checked. Next, PUMPH is called to adjust the pressure in those sections of the network which are supplied through a single pump whose cost is to be included in the optimization. If the minimum pressure in a pattern is less than the pressure tolerance for maximum sizes in each group, the program prints "MAXIMUM SIZES ARE INSUFFICIENT IN PATTERN X," where X is the pattern number. Program control then returns to the optimization menu. Otherwise, sizes are enumerated beginning with the size in the first group assigned to the smallest size in the group (i.e., ICS(1) = the highest size number), and subroutine SIZE is called again to assign the sizes and characteristic pipe coefficients to each group. Loading patterns are again enumerated, and water uses are assigned. Then the pressure distribution is calculated for all groups assigned their maximum sizes, except one which is assigned the minimum size in the group. If the minimum pressure is less than the pressure tolerance and the size of the group has reached the second largest size, the number of sizes in the group (array NS) is set to 1. If the minimum pressure is less than the pressure tolerance, yet the size of the group has not reached the second largest size, the size will be eliminated and the next larger size in the group will be tested. If the pressures are sufficient, POLD records the lowest pressure that occurred in all loading patterns, and MOLD records the corresponding pattern number. If all patterns have minimum pressures larger than zero, OPTINT accumulates total cost (present worth of pumping cost plus pipe cost) of the system as variable C9. If C9 is less than C8 (the cost of the so far least expensive solution, which met all requirements), the size combination, ICS, is recorded under IBS, the lowest pressure under BESTP, and the pattern number under PAT. OPTINT then calls on SOQU to test the solution for inclusion in the queue of Pareto Optimal solutions. If SOQU finds the combination to be Pareto Optimal, the combination is stored in array ISS, the corresponding pressure in array SPR, the cost in SCO, and pattern number in ISP. The following example will help illustrate the test on size range. The following group sizes are given:

Group #	Sizes, inches			
1		10	8	6	4
2	12	10	8	6	
3				6	4

Initially, the ICS array contains:

	Corresponding Size, inches
ICS(1) = 1	10
ICS(2) = 1	12
ICS(3) = 1	6

If the minimum pressure is greater than the pressure tolerance (i.e., P8 > R22) after computing the pressure distribution for this size combination, the size combination used for the next pressure distribution calculation is:

	Corresponding Size
ICS(1) = 4	4
ICS(2) = 1	12
ICS(3) = 1	6

If P8 < R22, after computing the pressure distribution, the size of 4 inches in group 1 can be eliminated, and the size number for group 1 will now become 3 such that group sizes are:

	Corresponding Size
ICS(1) = 3	6
ICS(2) = 1	12
ICS(3) = 1	6

Testing in this manner will continue until no more sizes in group 1 can be eliminated (i.e., P8 is greater than R22 for each combination) or until the highest size (10 inches) is the only remaining size in group 1. At [illegible] point, group 2 is assigned its minimum size of 6 inches (ICS [illegible] ing will continue with group 2 until pressure requirements are [illegible] the maximum size of 12 inches remains in the group. Finally [illegible] tested.

(3) Initializing queue of nonfunctional com[illegible] initializes a queue of nonfunctional combinations [illegible] tions of pipe sizes (up to 100 combinations [illegible] the pressure requirement (i.e., P8 < R22) [illegible] in array IFS refers to the combination [illegible] subscript refers to the group number [illegible] combination is less expensive than [illegible] bination will be compared against [illegible] functional combination is [illegible] sizes of the present combina[illegible]

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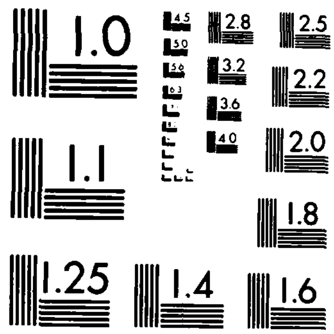

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

pressure requirement either. There will be no need to check the pressure distribution for this size combination. Nonfunctional combinations are generated by holding the size of one group at its maximum, while all other sizes are reduced together, one size at a time, until a nonfunctional combination is encountered. Then the next group is kept at its maximum size, etc. The following example helps to illustrate the procedure. It is assumed that the following sizes are assigned to groups 1 through 3:

Group 1:	8	6	4	
2:	10	8		
3:	12	10	8	6

First, the size of the highest group number (in this example, group 3) is kept at its maximum, and other groups are assigned the second largest pipe size, then the third largest size. If a group reaches its minimum size before other groups, its size is kept at the minimum size. Size combinations corresponding to ICS are shown below. (Subscript on ICS is the group number.)

Group #	ICS	Size inches	ICS	Size inches
1	2	6	3	4
2	2	8	2	8
3	1	12	1	12

Then, the next group number (here, group 2) is kept at the maximum.

Group #	ICS	Size inches	ICS	Size inches	ICS	Size inches
1	2	6	3	4	3	4
2	1	10	1	10	1	10
3	2	10	3	8	4	6

Finally, group 1 is kept at its maximum, while the other group sizes are reduced.

Group #	ICS	Size inches	ICS	Size inches	ICS	Size inches
1	1	8	1	8	1	8
2	2	8	2	8	2	8
3	2	10	3	8	4	6

This goes on until a few nonfunctional combinations are available.

b. Subroutine ENUMER. After OPTINT has finished, return is made to OPTRUN where subroutine ENUMER is called to enumerate and test all possible combinations. ENUMER accumulates system cost and pumping cost, and compares these to the cost of the best functional solution, multiplied by the cost factor R23, the tolerance within which solutions are saved as possible Pareto Optimal. If the sum is larger than the product of R23 and C8, the combination is not considered as a potential optimum, and the program accumulates cost for

the next combination. Otherwise, the routine enters the test against the nonfunctional system, and subroutine QUEU is called. If the combination passes the test against nonfunctional systems, it undergoes a pressure test. Subroutine SIZE is called to assign pipe sizes according to array ICS, and then subroutine OPTBAL, which in turn calls EQSOLV to determine pressure distribution. Based on the outcome of the balancing for all loadings, ENUMER may update the best functional solution and the queue of Pareto Optimal solutions, or the queue of nonfunctional solutions. Inclusion in the queue of Pareto Optimal solutions is accomplished by calling subroutine SOQU. After enumerating and testing, return is made to OPTRUN to call OPTERM.

c. Subroutine OPTERM. Once the optimal solution is determined, OPTERM assigns the optimal combination of pipe sizes (stored in array IBS) to array ICS and the water use distribution for the loading pattern that generated the lowest pressure to array DO. The routine then computes the pressure distribution and prints the pipe sizes for the best functional solution as well as the the sizes for the Pareto Optimal solutions. OPTERM calls on OPTBAL, which in turn calls EQSOLV to update the pressure computations, PUMPH to update pressure computations, and RESUL to generate the list of sizes in the output string, OUTP. Following execution of OPTERM, control returns to OPTRUN, and then to OPTIMI to display the optimization menu.

28-23. Printing Input Data. When PRINT OPT. DATA (ST(1:1)='2') is chosen from the optimization menu, program control passes to subroutine OPTPRN where the user's optimization data are printed. The group number and those pipes (user numbers) that belong to the group are displayed. OPTPRN calls subroutine OUT to store pipes in the output string, OUTP. OPTPRN then prints price function number and pipes (user numbers) assigned to each price function. If the pipes are not assigned to any price function, OPTPRN assigns them to the default price function 1. Subroutine SIZEL is called to generate a list of sizes to be printed so that sizes assigned to each groups may be displayed. Loads and minimum pressures for all nodes that have been assigned a minimum pressure and/or have an output different from the one used in the simulation routine are printed. For links that are pumps, the efficiency is printed, as well as the the percent time running for each loading pattern. Lastly, the routine prints Hazen-Williams coefficients of cleaned lined pipes, and the pressure tolerance and cost tolerance used in the formation of the queue of the Pareto Optimal solutions.

28-24. Storing Data. When storing optimization data, subroutine OPTIMI calls subroutine OPTSTO. Optimization data are stored in a formatted, sequential access file opened on device 1 under a name the user selects. On the first line of the file, OPTSTO stores MUNU (the number of loading patterns), IGR (the number of groups), R22 (the pressure tolerance), and R23 (the cost tolerance multiplier) using a 2I3,2E14.7 format. Stored next are the arrays XP (minimum pressure) and DM (output for loading pattern) with a 4E14.7 specification. OPTSTO then stores the pump arrays, EF and PT (4E14.7 format), occupying as many 20 rows, and 150 elements of the array SI (4E14.7 format). The following line contains the number of sizes in each group, NS, and then HWCC. Lastly, the routine stores the arrays IGROU and ICATE with a 10I3

```
  3  5-0.3000000E+01  0.1030000E+01                                      MUNU,IGR,R22,R23
 0.5000000E+02  0.1000000E+13  0.5000000E+02  0.1000000E+13
 0.2000000E+02  0.1000000E+13 -0.1000000E+11  0.1000000E+13
-0.1000000E+11  0.1000000E+13  0.5000000E+02  0.1000000E+03
 0.5000000E+02  0.7000000E+02  0.2000000E+02  0.1000000E+03
-0.1000000E+11  0.1000000E+03 -0.1000000E+11  0.1000000E+03
 0.5000000E+02  0.2000000E+03  0.5000000E+02  0.1400000E+03
 0.2000000E+02  0.2000000E+03 -0.1000000E+11  0.2000000E+03
-0.1000000E+11  0.2000000E+03  0.5000000E+02  0.0000000E+00
 0.5000000E+02  0.0000000E+00  0.2000000E+02  0.0000000E+00
-0.1000000E+11  0.0000000E+00 -0.1000000E+11  0.0000000E+00
 0.5000000E+02  0.3000000E+03  0.5000000E+02  0.2100000E+03
 0.2000000E+02  0.3000000E+03 -0.1000000E+11  0.3000000E+03  XP,DM,XP,DM
-0.1000000E+11  0.3000000E+03  0.5000000E+02  0.0000000E+00
 0.5000000E+02  0.0000000E+00  0.2000000E+02  0.0000000E+00
-0.1000000E+11  0.0000000E+00 -0.1000000E+11  0.0000000E+00
 0.5000000E+02  0.2000000E+03  0.5000000E+02  0.1400000E+03
 0.1500000E+02  0.1200000E+04 -0.1000000E+11  0.2000000E+03
-0.1000000E+11  0.2000000E+03  0.5000000E+02  0.0000000E+00
 0.5000000E+02  0.0000000E+00  0.2000000E+02  0.0000000E+00
-0.1000000E+11  0.0000000E+00 -0.1000000E+11  0.0000000E+00
 0.5000000E+02  0.3000000E+03  0.5000000E+02  0.2100000E+03
 0.2000000E+02  0.3000000E+03 -0.1000000E+11  0.3000000E+03
-0.1000000E+11  0.3000000E+03  0.5000000E+02  0.5000000E+03
 0.5000000E+02  0.3500000E+03  0.2000000E+02  0.5000000E+03
-0.1000000E+11  0.5000000E+03 -0.1000000E+11  0.5000000E+03
 0.1000000E+03  0.0000000E+00  0.0000000E+00  0.0000000E+00
 0.0000000E+00  0.0000000E+00  0.1000000E+03  0.0000000E+00
 0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
 0.1000000E+03  0.0000000E+00  0.0000000E+00  0.0000000E+00
 0.0000000E+00  0.0000000E+00  0.1000000E+03  0.0000000E+00
 0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
 0.1000000E+03  0.0000000E+00  0.0000000E+00  0.0000000E+00
 0.0000000E+00  0.0000000E+00  0.8000000E+02  0.5000000E+02  EF,PT,PT,PT
 0.5000000E+02  0.0000000E+00  0.0000000E+00  0.0000000E+00
 0.1000000E+03  0.0000000E+00  0.0000000E+00  0.0000000E+00
 0.0000000E+00  0.0000000E+00  0.1000000E+03  0.0000000E+00
 0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
 0.1000000E+03  0.0000000E+00  0.0000000E+00  0.0000000E+00
 0.0000000E+00  0.0000000E+00  0.1000000E+03  0.0000000E+00
 0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
 0.1000000E+03  0.0000000E+00  0.0000000E+00  0.0000000E+00
 0.0000000E+00  0.0000000E+00
 0.1400000E+02  0.1200000E+02  0.6000000E+01  0.6000000E+01
 0.6000000E+01  0.0000000E+00  0.0000000E+00  0.0000000E+00
 0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  SI Array
 0.0000000E+00  0.0000000E+00  0.0000000E+00  0.1600000E+02
 0.1400000E+02  0.8000000E+01  0.8000000E+01  0.8000000E+01
```

Figure 28-10. Formatted file created with subroutine OPTSTO (Continued)

```
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.1800000E+02   0.1600000E+02
0.1000000E+02   0.1000000E+02   0.1000000E+02   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   SI Array
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
0.0000000E+00   0.0000000E+00

 3  3  3  3  3  0  0  0  0  0  0  0  0  0  0  0.120E+03      NS Array,HWCC
 1  1  2  1  3  1  2  1  3  1                                IGROU,ICATE,
 0  1  4  1  5  1  3  1  0  1                                IGROU,
 3  1                                                        ICATE, ...
```

Figure 28-10. (Concluded)

format specification. Figure 28-10 shows an example of a formatted file created with OPTSTO. Optimization data on the file are taken from example 3 in the User's Guide. After storing the data, the program rewinds and closes the file and transfers program control back to subroutine OPTIMI.

28-25. Retrieving Data. When the RETRIEVE OPT. DATA (ST(1:1)='4') option is chosen, control passes to subroutine OPTRET. After prompting for the name of a file on which the optimization data were stored with subroutine OPTSTO, OPTRET proceeds to open the formatted file on device 1 and retrieves the data using the same format specifications as OPTSTO. When opening the file, OPTSTO tests to be sure the file is accessible. If it is not accessible, OPTSTO displays an error message. After reading, OPTRET transfers program control back to OPTIMI where the optimization menu is displayed.

28-26. Cost Data. If the ENTER/MODIFY COST DATA (ST(1:1)='5') option is chosen, control passes to subroutine COSTDA. Execution of this routine and the ones it calls is described in paragraphs 28-12 through 28-17. The last two options, PROGRAM CONTROL and TERMINATE PROGRAM, are described in paragraphs 28-10 and 28-11, respectively.

Section 5. Extended Period (Time) Simulation

28-27. Introduction. When the user selects TIME SIMULATION (ST(1:1)='4') from the main program menu, WADISO calls subroutine TIMENU. TIMENU verifies that the steady-state simulation data have been entered by checking that the number of nodes in the system (O(2)) is greater than 1. If O(2) is not greater than 1, a message is displayed, and control returns to the main program menu. Otherwise, TIMEIN displays the menu for the extended period simulation. Based on the user's selection, TIMENU calls on appropriate subroutines to carry out the extended period simulation operation. Figure 28-11 shows a general flowchart describing execution of the extended period simulation routines. Paragraphs 28-28 through 28-34 document the portion of the program code dealing with the options shown in the time simulation menu.

28-28. Data Input. After the ENTER, MODIFY DATA (ST(1:1)='1') option has been chosen from the time simulation menu, TIMENU calls TIMEIN to read in the time data, decompose the string containing the input, and assign numeric values in the input string to the extended period simulation parameters.

a. Reading of Input String. TIMEIN initially presents the keyword, contained in KTYPE, as DURA in the time simulation prompt. The initial characters stored in the input string, ST, are analyzed to verify that they are valid. If the input string begins with alphanumerical characters, a check is made to verify that a valid keyword has been entered by comparing the first four letters of the string against the valid keywords. If an invalid keyword has been entered, the user is notified, and control returns to the input prompt. Otherwise, the input string is decomposed.

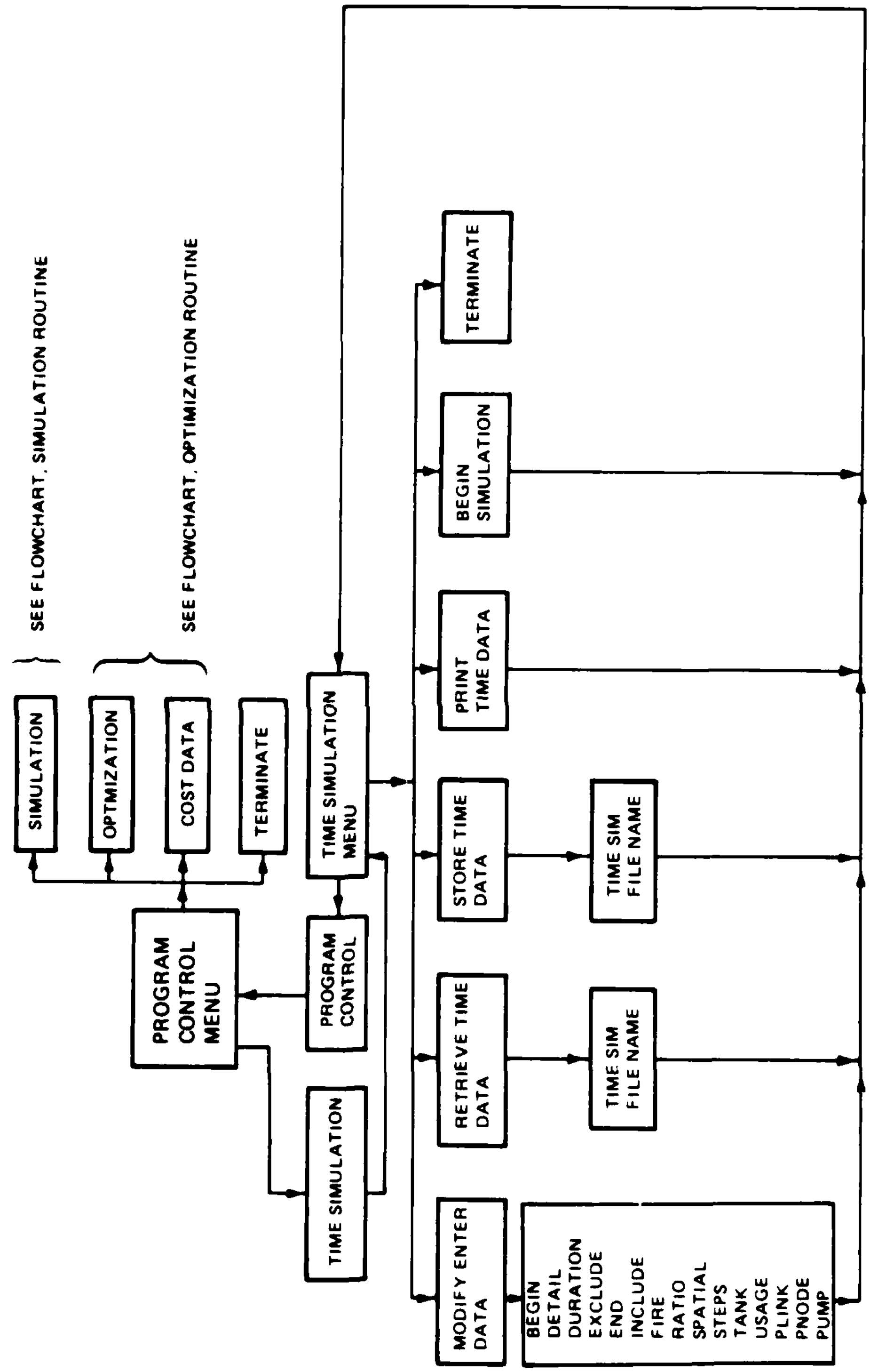

Figure 28-11. Flowchart, time simulation routine

b. Decomposing of Input String. To decompose the input string, TIMEIN calls on subroutine DECINP. Passed into DECINP is the input string, ST, and returned is the number of numeric values, L, and their values stored in the array VALUE as well as the keyword, contained in KTYPE, and the second keyword (if entered) as KTYPF.

c. Assignment of Data. After decomposing the input string, TIMEIN determines which keyword was entered and assigns the numerical values in the input string to variables associated with the keyword. TIMEIN tests the numerical values to verify that they are reasonable and that the correct format for the keyword was used. After making assignments, control returns to the input prompt, and steps a, b, and c described above are repeated until the keyword END has been entered.

d. Ending Time Data Input. When keyword END is entered, TIMEIN tests if time steps and duration were entered. If they were not, TIMEIN defaults to a duration of 24 hours with 24 time steps. Next, TIMEIN tests if any nodes were not assigned to a loading pattern (IPAT (I) = 0, where I refers to the internal node number). If so, the default pattern of 1 is used and loading factors in array XLOF are assigned to the default loading factors in array XDEFAL. Array LPAT, subscripted with the pattern number assigned to the node (IPAT), is flagged with a 1 indicating that loading factors have been assigned to a pattern (e.g., LPAT(2)=1 indicates that loading patterns for the second pattern have been entered). Tank nodes are also checked to verify that upper and lower water levels were entered and are reasonable (e.g., no upper limits smaller than lower limits) and that each tank has a cross-sectional area. If no value was specified with the RATIO keyword, RATIO is set to 1. TIMEIN then verifies if fire specifications are consistent by checking that the start of the fire is not later than the number of steps and that the end of the fire is not later than the number of steps. The user is notified of any inconsistency in the data. Next, if any pipes are to be excluded, TIMEIN verifies that the ending time of exclusion, TEE, is later than the beginning time of exclusion, TEB, and that both times are earlier than the total time, TMAX. Lastly, TIMEIN tests if pump data are correct. For pumps controlled by time, TIMEIN verifies that the time at which the pump starts running is less than the duration and that the time at which the pump stops running is less than the duration. For pumps controlled by tank water levels, TIMEIN checks if the tank water levels turning the pump on and off are between the maximum and minimum water levels specified with keyword TANK. TIMEIN displays a warning message if any inconsistency in the pump data is found. Program control returns to the time simulation menu.

28-29. Simulation. When BEGIN SIMULATION (ST(1:1)='O') is chosen from the time simulation menu, TIMENU calls on TIMSIM to perform flow and pressure calculations taking into consideration pumps turning off and on, varying water use patterns, fire flows, and fluctuations in water levels in tanks. A description of the steps involved in subroutine TIMSIM is presented here. The steps are described in the order in which they take place in subroutine TIMSIM.

a. Initial Closing of Pipes. TIMSIM calls subroutine PIPEX at the beginning of the simulation to close pipes that are to be excluded at time zero hours from the extended period simulation. PIPEX excludes pipes from the simulation by assigning 1E10 to CP, the characteristic pipe coefficient, and 1E-10 to A, the entry in the coefficient matrix, so the routine that solves the hydraulic equations, EQSOLV, will exclude these pipes from the system.

b. Initial Pump Controls. TIMSIM calls subroutine PUMPCO at the beginning of the simulation to determine if pumps should be turned on or off. Pumps are initially turned on or off based on the user's input with keyword BEGIN. Variable PUBE is set to "ON" if the pump is initially turned on and to "OFF" if the pump is initially turned off. For additional details on turning pumps on and off, see paragraph 28-29j.

c. Updating Time Step. Variable ILC records the number of user-defined time steps that have taken place. TIMSIM initially sets ILC to zero and increments it by one prior to the first balancing in the extended period simulation and every time the elapsed time of the extended period simulation corresponds to the step size defined by the user.

d. Loading Patterns and Fire Flows. TIMSIM calls subroutine LOAD at the beginning of each user-defined time step to multiply water uses by relative loading factors and to check for first flows at nodes. Loading factors are entered in TIMEIN and assigned to the doubly subscripted array XLOF. The first subscript refers to the time step, and the second to the pattern assigned to the water use node. When the time step counter, ILC, is increased, LOAD multiplies the water uses at nodes by their respective loading factors for time step ILC. If a node is assigned a fire flow for time step ILC, array FF, the fire flow in cubic feet per second, subscripted with the node assigned the fire flow, is added to the water use at that node. Array FF is subtracted from the water use at the node (variable DO) when the ending time of the fire, IDF, exceeds ILC.

e. Balancing. TIMSIM calls EQSOLV to compute heads at all nontank nodes and flows through links. EQSOLV is used to balance steady-state simulation, optimization, and extended period simulation. To indicate that balancing is for the extended period simulation, TIMSIM sets variable IFOP to -1 and passes it in the argument list to subroutine EQSOLV as a flag indicating that balancing is for time simulation and not steady state or optimization. (See paragraph 28-5b for additional details on balancing.)

f. Updating Total Time of Simulation. TIMSIM records the time of the simulation, in minutes, with variable TOT. TOT is updated by a value of DT, the internal time step. Initially, DT = 0.01 minute and TOT = -0.01 minute; thus, after updating, TOT = 0 minutes. When TOT is updated after the next balancing, DT has been determined by subroutine TIMSTE (see paragraph 28-29m).

g. Printout of Flows and Pressures. If the user has entered nodes or links with keywords PNODE and PLINK in subroutine TIMEIN, TIMSIM calls on TSOUT to display flows through the specified link and pressures (or tank water

elevations) at specified nodes. TSOUT also displays the time at which flows and heads are printed. If (keyword DETAIL) printing of head at each time step has been specified, TIMSIM calls TSOUT when the time of the simulation is incremented with the variable time step DT.

h. Updating Water Levels of Variable-Level Tanks. To update water levels in tanks, outflow from (or inflow to) a variable-level tank is needed. TIMSIM calculates inflow or outflow (variable DO in cubic feet per second), assumed constant over DT with this equation:

$$DO = (HE_B - HE_E)/CP^{0.54} \tag{28-2}$$

where

HE = total hydraulic head, feet
B = beginning node number of pipe connected to tank
E = ending node number of pipe connected to tank
CP = characteristic pipe coefficient, feet/cubic foot per second$^{1.85}$

Outflow from a tank is indicated by DO < 0; DO > 0 indicates inflow to a tank. After computing DO, TIMSIM updates the hydraulic head at all variable-level tanks with this relationship:

$$HE_B = HE_B + DO*DT*60/ART \tag{28-3}$$

where

DT = time step, minutes
ART = tank area assuming cylindrical tank, square feet

At the beginning of each user-defined time step, just after relative loading factors have been applied to water uses, and at the end of each user-defined time step, TIMSIM records tank heads under variable TAH. TAH is a doubly subscripted array, with the first subscript corresponding to the tank number and the second to the number of the time step.

i. Tank Controls. If the head at a tank node is greater than the upper tank water level (variable UPL specified in TIMEIN) plus the elevation of the tank node (i.e., tank is full) and water is flowing into the tank, the link connecting the tank to the system is disconnected (closed) by assigning 1E20 to CP, the characteristic pipe coefficient. The link connecting the tank to the system is also disconnected when the hydraulic head at the tank node falls below the lower tank water level (variable XLOL) plus the elevation of the tank node (i.e., tank is empty) and water is flowing out of the tank. If a tank is disconnected full, it is reconnected when the hydraulic head of the ending node of the link connecting the tank to the system is greater than the hydraulic head of the beginning node of the link (the tank node). If a tank is disconnected empty, it is reconnected when water begins flowing into the tank (i.e., the head at the ending node of the link connecting the tank to the system exceeds the head at the beginning node of the link). When reconnecting the tank, TIMSIM opens the pipe connecting the tank to the system by computing a characteristic pipe coefficient with the Hazen-Williams equation.

$$CP = 4.72*L/(HW^{1.85}*D^{4.87}) \qquad (28\text{-}4)$$

where

L = length of pipe, feet
HW = Hazen-Williams coefficient factor
D = diameter of pipe, feet

j. Pump Controls. After updating tank heads, TIMSIM again calls PUMPCO to check if pumps should be turned on or off. If a pump is controlled by time, it is turned on when the total time, TOT/60, equals the time when the pump turns on, TPB (in hours), and turned off when TOT/60 equals TPE, the time in hours when the pump turns off. Pumps that are controlled by pressure or tank level (i.e., "pressure control") are turned on when the hydraulic grade line at the node controlling the pump falls below the on level specified by the user in TIMEIN and turned off when the hydraulic grade line at the node controlling the pump exceeds the off level specified by the user. The check for pressure control is made after the time control check so that pressure control will override time control. When pumps are turned on, XL, subscripted with the internal link number corresponding to the pump number, is set to 1 to flag that the pump is on. The corresponding pump element in array A is computed with this equation:

$$A = 1.85/\sqrt{b^2 - 2ac} \qquad (28\text{-}5)$$

where

a = coefficient of squared term in the pump characteristic equation
b = coefficient of linear term in the pump characteristic equation
c = constant in pump characteristic equation

PUMPCO sets the pump element in the A array to zero for pumps that are off so that the balancing routine will consider no flow through the pump link.

k. Excluding Pipes. Just as TIMSIM calls PUMPCO to perform a check on pump status after balancing, TIMSIM also calls PIPEX to check if it is time to exclude any pipes or if it is time for any previously excluded pipes (see paragraph 28-29a) to be included. PIPEX excludes (closes) pipes when TEB, the time in hours when a pipe closes, equals the total time, TOT, in minutes divided by 60. CP and A are assigned 1E10 and 1E-10, respectively, for closed pipes. PIPEX includes (opens) pipes when TEE, the time in hours when a pipe becomes included, equals TOT/60. For open pipes, PIPEX recalculates CP with the equation shown in paragraph 28-29i and assigns A to 1/CP. TEB and TEE are doubly subscripted arrays with the first subscript equal to the number corresponding to the order in which the pipe was entered and the second corresponding to the number of the pair of closed and open times.

l. Check for End of User Time Step and Beginning of Next. If a user-defined time step is about to end or has just begun, TIMSIM calls LOWP to record the lowest pressure and the node number where the lowest pressure

occurred. TIMSIM also records the status of each pump in variable PUST. If the time step is almost over, program control returns to steps beginning in paragraph 28-29c above. Otherwise, an internal time step, DT, is calculated.

m. Determining Internal Time Step. TIMSIM calls subroutine TIMSTE to calculate the internal time step, DT. TIMSTE uses several equations to calculate an internal time step and chooses the smallest value as DT. If the computed DT is smaller than 2.5 minutes, it is assigned to 2.5. TIMSIM predicts the time in minutes when a connected tank will become disconnected or when a pump controlled by tank level is to turn on or off with this equation:

$$DT = ART*(HC-HE)/(DO*60) \qquad (28\text{-}6)$$

where

HC = hydraulic grade line where tank becomes disconnected or, in the case of a pump, the hydraulic grade line of the tank controlling the pump where the pump turns on or off, feet
HE = present hydraulic grade line of tank, feet
DO = inflow to (or outflow from) tank; inflow is positive, outflow is negative, cubic feet per second

Equation 28-7 predicts the time in minutes when disconnected tanks become reconnected, or when pumps controlled by nontank nodes turn on or off.

$$DT = DT_p*(HE-HC)/(HE_p - HE) \qquad (28\text{-}7)$$

where

DT_p = previous internal time step, minutes
HE = present hydraulic grade line of tank (or hydraulic grade line of node controlling pump, feet
HC = hydraulic grade line where tank becomes connected or, in the case of a pump, the hydraulic grade line of the node controlling the pump where the pump turns on or off (on value when pump is off, off value when pump is on), feet
HE_p = previous hydraulic grade line of tank when DT_p was the time step, or, in the case of a pump, the previous hydraulic grade line of the node controlling the pump, feet

TIMSTE also uses Equation 28-7 to predict when PRVs will change status. The terms in the equation are defined this way:

HE = present hydraulic grade line of node immediately downstream of the PRV link, feet
HC = PRV setting, feet
HE_p = previous hydraulic grade line of node immediately downstream of the PRV link, feet

To determine the time until time-controlled pumps or pipes will change status, TIMSTE takes the difference between the smallest on or off time greater than the total time of simulation and the total time of the simulation. TIMSTE

performs a final calculation of the time step based on inflows and outflows to tanks. This equation is used:

$$DT = DT_p/(DD/DM) \qquad (28\text{-}8)$$

where

DT_p = previous variable time step, minutes (initially set to 2.5 minutes)

DD = absolute value of the greatest change in outflows from (or inflows to) all variable tanks between the previous time step and current time step, cubic feet per second

DM = greatest single outflow from (or inflow to) all variable-level tanks, cubic feet per second

n. Final Output. When the extended period simulation is over (i.e., ILC > the number of steps, NSTEP), TIMSIM displays a table showing the time at the end and beginning of a user-defined time step, the minimum pressure in the system, the node number where the minimum pressure occurred, and tank water levels in the system for each time.

o. Viewing of Flows and Pressure for a Time Step. TIMSIM undertakes these steps to view flows and pressures for a time step:

(1) Calls PIPEX to reset characteristic pipe coefficients and elements in the A array for all links to their original values.

(2) Excludes any pipes specified by user for indicated time step.

(3) Calls LOAD to assign relative loading factors to water use nodes and assign any fire flows for the indicated time step.

(4) Assigns hydraulic grade lines, recorded in variable TAH, to tanks in the system for indicated time step.

(5) Checks water levels in tanks with the maximum and minimum levels to see if pipe connecting tank to the system should be closed.

(6) Assigns status, recorded in variable PUST, to pumps and turns them off for PUST = -1.

(7) Calls EQSOLV to balance the system.

(8) Calls PRNOUT to display an output table showing flows through all links and pressures at all nodes in the system.

28-30. Printing Time Data. When PRINT TIME DATA (ST(1:1)='2') is chosen from the time simulation menu, TIMENU calls subroutine TIMEOT. TIMEOT prints the simulation duration, TMAX, in hours; the time step size, TSLF, in hours; and the number of time steps, NSTEP. TIMEOT tests if array LPAT, subscripted with the pattern number, contains a 1 to determine which usage patterns contain loading factors. Pattern numbers of usage patterns which contain loading

factors are stored in array LIST. TIMEOT then prints the pattern numbers and loading factors for each time step. Next, TIMEOT prints tank data consisting of NTANK, the tank node; UPL, the upper tank water level in feet; XLOL, the lower tank water level in feet; ART, the tank area in square feet and HETI, the initial tank water level in feet. If any fires were specified, TIMEOT prints the node number supplying the fire flow, NFIRE; the starting time step of the fire, ITF; the duration steps of the fire, IDF; and the fire flow, FLOW, in gallons per minute. TIMEOT prints the numbers of the links that are out of service contained in array IPEX. Next, the routine prints water use node numbers (contained in array INO), excluding constant head nodes (i.e., DO > 1E10), and usage patterns assigned to them. For pumps for which time control has been specified, TIMEOT displays the user's pump number, NPUMP; the starting time step of pumping, ITP; and the ending time step of pumping, IDP. If node pressure or tank water level control is specified, the level at which the pump turns on, HEON, and the level at which the pump turns off, HEOF, are displayed. Lastly, the routine prints the user's node numbers and link numbers (array NUSR) that have been assigned for printout at the end of each time step. After printing, control returns to the time simulation menu.

28-31. Storing Time Data. When STORE TIME DATA (ST(1:1)='3') is chosen from the time menu, TIMENU calls STOTIM to store the extended period simulation parameters. After prompting the user to enter the name of a file on which the data will be stored, STOTIM proceeds to open the file as a formatted, sequential-access file on device 1. On line 1 of the file, STOTIM stores TMAX, the duration of the simulation; TSLF, the time step size; NSTEP, the number of steps; and RATIO, the constant specified with keyword RATIO. STOTIM uses a 2F7.3, I4, F7.3 format specification. STOTIM stores the number of nodes, O(2), and the number of the use pattern, contained in array IPAT, assigned to each node using a 16I4 format. Next, the number of loading patterns, NP, and the loading factors, contained in array XLOF, are stored using a I1, (5F7.3) format specification. After storing the loading factors, STOTIM stores elements of the LPAT array with a 5I4 format specification. Fire data, consisting of the number of fires (NF), fire flows (FF), starting time step of fires (ITF), and ending time step of fires (IDF), are then stored using a I1, (3I4, E16.9) format. Tank data, consisting of the number of tanks (NTN), tank node numbers (NTANK), upper tank water levels (UPL), lower tank water levels (XLOL), tank areas (ART), and initial tank water levels (HETI), are then stored using a I4, (I4, 4E16.9) format. The next line of the file contains the number of links that are to be excluded, ICPE, and their link numbers, IPEX. STOTIM uses a 16I4 format specification. STOTIM then stores the closing times, TEB, and opening times, TEE, for excluded links with a 12F6.2 format specification. The number of pumps (NPUC), their user numbers (NPUMP), the user node number controlling the pump, and the initial status of the pump (PUBE) are then stored using a I4, 5(2I4, A3) format specification. STOTIM next stores the starting hour of pump running, TPB, and the ending hour of pump running, TPE, using a 12F6.2 format specification. STOTIM then stores the head turning pumps on, HEON, and the head turning pumps off, HEOF, using a 4E16.9 format specification. User link and node numbers, NUSR, that will have flows or heads printed out are stored with a 10I4 format. On the remaining lines of the file, STOTIM stores the character arrays NOLI (containing NODE or LINK) and UNIT (containing GPM, FT, PSI, or "   ") using a 2(A4,A3) format.

Figure 28-12 shows a formatted file created with STOTIM containing time data from example 6 in the User's Guide. After storing the data, STOTIM closes and rewinds the file, and control returns to the time simulation menu.

28-32. Retrieving Time Data. If the RETRIEVE TIME DATA (ST(1:1)='4') option is chosen from the time simulation menu, control passes to subroutine RETIME to retrieve the extended period simulation parameters. RETIME prompts the user for a name of a file that was created with subroutine STOTIM. RETIME opens the file, rewinds the file, and reads the parameters using the format specifications described in paragraph 28-31. If RETIME cannot access the file, an error message is displayed, and control returns to the time simulation menu.

28-33. Program Control. See paragraph 28-10.

28-34. Termination. See paragraph 28-11.

```
 24.000  1.000   24    1.000
  13     0  0    0   1   1  1  1  1  1  1  0 1 1                   TMAX, TSLF, NSTEP,
1 1,000  1.100   1.200   1.300  1.400                              RATIO 0(2), IPAT
  1.500  1.600   1.500   1.400  1.300                              Array NP, XLOF
  1.200  1.100   1.000   0.900  0.800                              Array
  0.700  0.600   0.500   0.400  0.500
  0.600  0.700   0.800   0.900
   1     0       0       0                                         LPT Array
1 22   10      11    0.100000000E+04                               NF, NFIRE, ITF,
                                                                     IDF, FF
   3  25 0.130000000E+03 0.800000000E+02 0.20000000000E+04 0.1100000000E+03 NTN; UPL, XLOL, ART
                                                                     Arrays
   2 0.150000000E+03 0.100000000E+03 0.200000000E+04 0.120000000E+03
   9 0.000000000E+00 0.000000000E+00 0.100000000E+11 0.000000000E+00
    0                                                              ICPE
    1     9    20FF                                                NPUC; NPUMP, NOPU,
                                                                     PUBE, Arrays
  -1.00 -1.00 -1.00 -1.00 -1.00 -1.00 -1.00 -1,00 -1.00 -1.00 -1.00 -1.00  TPB, TPE Array
  -1.00 -1.00
  0.110000000E+03 0.140000000E+03                                  HEON, NEOF Array
    2  25  10  12 110  24  10   9   0   0                          NUSR Array
NODE FTNODE FT                                                     NOLI, UNIT Arrays
NODEPSINODEPSI
LINKGPMLINKGPM
LINKGPMLINKGPM
```

Figure 28-12. Formatted file created with subroutine STOTIM

Section 6. Definition of Subroutines, Variables, and Parameters

28-35. Introduction. This section describes subroutines, variables, and parameters in the WADISO program. Paragraph 28-36 provides brief descriptions of all subroutines used in the program; paragraph 28-37 defines variables in the WADISO program; and paragraph 28-38 describes when to modify the parameters in the program.

28-36. Subroutine Descriptions. Executive subroutines are called by several subroutines and are presented first, followed by descriptions of steady-state simulation subroutines, cost subroutines, optimization subroutines, and extended period simulation subroutines.

a. Executive Subroutines.

BLANK - Called whenever a blank line is entered by the user. Blanks will notify the user that input is required. Called by COSTDA, INPCST, INPDAT, OPTIMI, OPTCST, OPTMOD, OPTRET, OPTSTO, RETCST, RETDAT, RETIME, SIMULA, STOCST, STODAT, STOTIM, TIMEIN, TIMENU, and WADISO.

DECINP - Called from subroutine INPCST (the cost input routine), from OPTMOD (the optimization input routine), or from TIMEIN (the extended period simulation input routine) to decompose the input string into keywords and numerical data.

EQSOLV - Called from SIMBAL or OPTBAL to solve the continuity equations for unknown hydraulic heads. New coefficients in the matrix are calculated based on estimated flow rates computed from the new heads. The routine is repeated until the desired pressure and flow accuracy are reached.

JJ - A function called by INPDAT and DECINP to locate in the input string, ST, the first occurrence of character T1 (a blank) and T2 (a comma) and return with the smaller of these two values.

KEYWRD - Called from SIMULA, INPCST, OPTMOD, and TIMEIN, KEYWRD; displays all keywords that can be used in the routine which calls it. If a keyword has been entered followed by no numerical data, KEYWRD is also called to display the correct format(s) for the keyword.

PARALE - When balancing a system, PARALE is called by subroutines SIMBAL, EQSOLV, and OPTBAL to locate links with the same beginning and ending nodes to add to the corresponding coefficients, A, in the coefficient matrix and to store the sum under the coefficient of the link with the higher internal link number equal to zero.

TERMIN - Called from COSTDA, OPTIMI, SIMULA, TIMENU and WADISO to terminate the program. In addition, on the Cybernet, TERMIN prints a message reminding user to transfer local files to permanent storage.

WADISO - WADISO is the main program. It displays the maximum node and pipe numbers, the maximum number of nodes and pipes, the program version, and the main program menu. Print controls also may be changed within WADISO. Transfer to COSTDA, OPTIMI, SIMULA, TERMIN, or TIMENU is made based on the user's selection from the main menu subroutine (Figure 28-13).

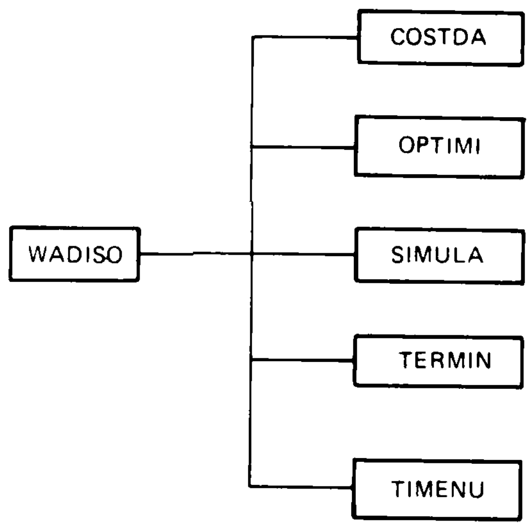

Figure 28-13. WADISO executive subroutines

b. Simulation Subroutines (Figure 28-14).

ERROR - Called from subroutine INPDAT, when the user has miskeyed some data. Subroutine ERROR will display the appropriate error message depending on the error made. Also, if only a keyword is entered with no data following, the correct format of the keyword is displayed with this subroutine.

INPDAT - Called from subroutine SIMULA when entering a new job or from subroutine MODIFY when modifying a system. Reading, decomposing, and analyzing of the input string are accomplished.

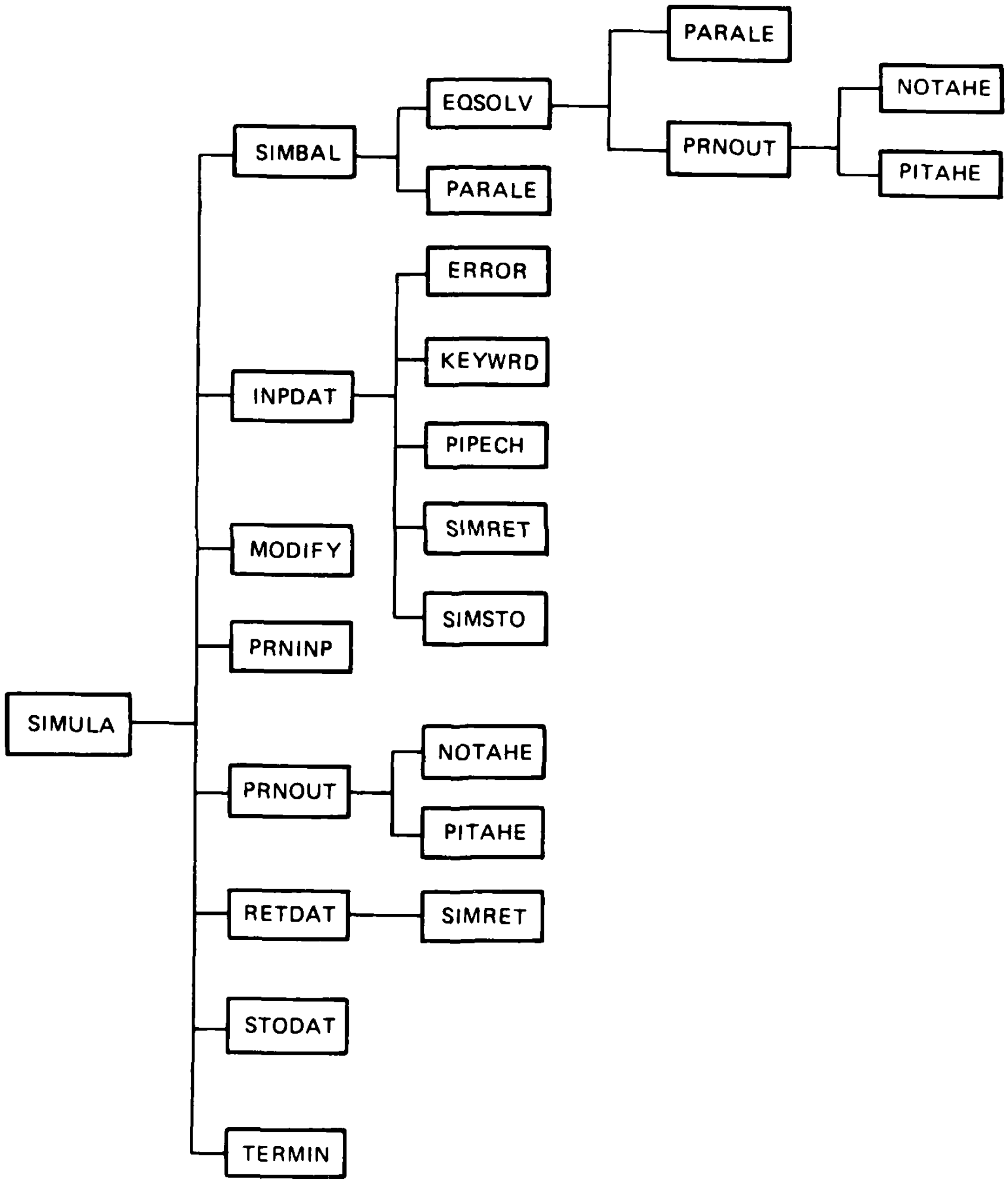

Figure 28-14. Simulation routine

MODIFY - Called from subroutine SIMULA when the modify option is chosen. MODIFY expands the node and pipe data into the original format used in the data input.

NOTAHE - Called by PRNOUT, NOTAHE prints the table heading of the node table.

PIPECH - Called from INPDAT and checks whether a link with the same number was previously entered. If so, new data are retained.

PITAHE - Called by PRNOUT to print the heading of the link table.

PRNINP - Called from SIMULA when PRINT INPUT option is chosen. Prints a node table consisting of node numbers, elevation, output, and comments indicating the constant head points. Also displays a link table with link numbers, beginning and ending nodes, pipe diameters, pipe lengths, Hazen-Williams coefficients; indicates PRVs, pumps, or check valves if present.

PRNOUT - Called either from EQSOLV or from SIMULA when PRINT OUTPUT option is chosen from the selection menu. Displays the node table consisting of node numbers, elevation of nodes, outputs, elevation of hydraulic grade lines, heads, pressures, and comments to flag constant head nodes. In addition, prints a link table with link numbers, node numbers, diameters, lengths, Hazen-Williams coefficients, flows, velocities, and head losses.

RETDAT - Called from subroutine SIMULA, RETDAT retrieves all data from a formatted file opened on device 1 which was created with subroutine STODAT.

SIMBAL - Called by subroutine SIMULA; initiates the balancing routine by creating the characteristics of the sparse matrix in two steps. In step 1, all the user-defined links are entered into arrays N1 and N2. Zero entries in the coefficient matrix, needed during the Gaussian elimination procedure, are created in step 2.

SIMRET - Called from subroutine INPDAT to retrieve the data stored on a backup file; created by subroutine SIMSTO during the simulation input routine. Keying in "GET" will transfer control to this subroutine. Also, SIMRET may be called from RETDAT when attempting to retrieve a backup file created during the modify mode of the simulation routine.

SIMSTO - Called from subroutine INPDAT, after keying in "CREA," SIMSTO stores node data, numeric link data, and job name on a formatted, sequential-access file opened on device 1. If a file name follows the keyword CREA, data are stored on that file name; otherwise, the name SYSDA is used.

STODAT - Called from subroutine SIMULA, when the user has selected STORE DATA option, STODAT stores the job name, user numbers of beginning and ending nodes, user numbers of links, user numbers of node, the total hydraulic head, output, elevation, coefficient matrix, characteristic pipe coefficient, pipe diameters, lengths, and Hazen-Williams coefficients on a formatted, sequential-access file.

c. Cost Subroutines (Figure 28-15).

COSTDA - Subroutine COSTDA is called from the main program WADISO and subroutine OPTIMI. It prompts the user to enter new cost data or retrieve data, displays main menu for all cost options, and transfers control to the appropriate subroutine depending on the option chosen.

INPCST - Called from subroutine COSTDA, to display cost keyword prompt and read in cost input string. Assignments are made to variables based on the keyword entered.

PRNCST - Prints the cost data, which include the pipe sizes, price per linear foot, energy cost, time period, and interest rate (used in determining the present worth of pumping cost); called from COSTDA when PRINT DATA option is chosen from the cost menu.

RETCST - Retrieves cost data, stored on a formatted file created with subroutine STOCST, when the user selects RETRIEVE DATA option in the COSTDA routine.

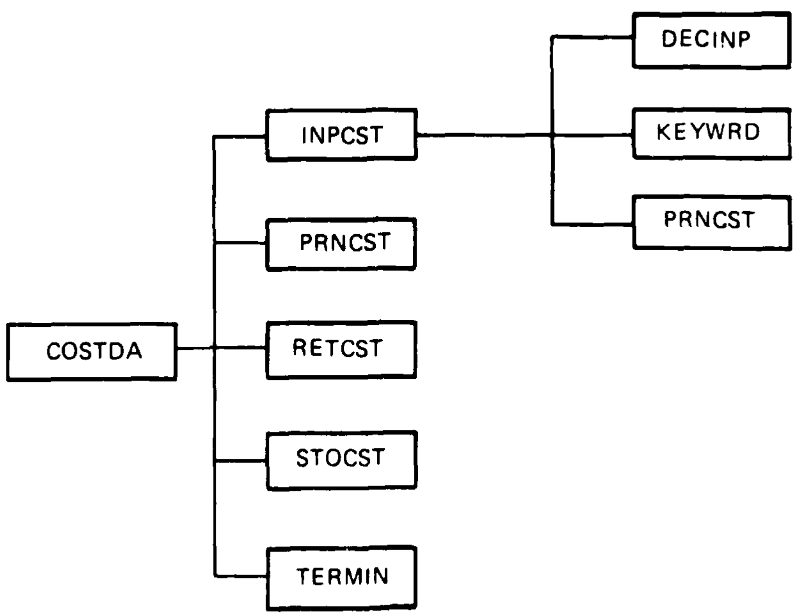

Figure 28-15. Cost routine

STOCST - Called from COSTDA to store all cost data on a user-selected file name as a formatted, sequential-access file opened on device 1. Number of sizes, number of price functions, pipe sizes, price per linear foot, energy cost, number of years, and interest rate are all stored.

d. Optimization Subroutines (Figure 28-16).

COSTDA - Called from subroutine OPTIMI, when ENTER/MODIFY COST option has been chosen and further described under the COST subroutine descriptions.

ENUMER - After the routine OPTINT has been executed, ENUMER is called from OPTIMI to continue with the optimization process. ENUMER enumerates and tests all possible combinations. System cost and pressure distribution are also determined.

INTER - Called from subroutine ENUMER. Prints the best solution.

OPTBAL - Called from subroutines OPTINT, ENUMER, AND OPTERM, to initialize diagonal members in the matrix (S array) and the right-hand side of the continuity equation (G array). OPTBAL will call EQSOLV to calculate the pressure distribution.

OPTINT - Called from subroutine OPTRUN, when a system is to be optimized. Subroutine OPTINT accumulates cost of combinations. Pipe or cleaning/lining cost is determined and sizes are sorted; duplicate sizes and sizes that are more expensive than the next larger size in the group are eliminated. In addition, OPTINT tests whether some small sizes in each group can be ruled out. All groups but one are assigned their maximum sizes, and the group to be tested is assigned the smallest size. If pressure requirements can be met for all loading patterns, the smallest size cannot be eliminated; otherwise, it can be. Lastly, OPTINT stores combinations of pipe sizes that did not meet the pressure requirements.

OPTERM - After the optimum solution has been found, OPTERM is called from OPTIMI. The routine assigns pipe sizes of the functional combinations to array ICS and water use rates for the pattern which generated the lowest pressure to array DO. Pressure distributions are recalculated, and pipe sizes, cost, and pressures for the best functional solution as well the Pareto Optimal solution are displayed.

OPTIMI - Called from the main program WADISO, OPTIMI initializes optimization variables, displays the optimization option menu, and transfers control to subroutines depending on option selected by the user.

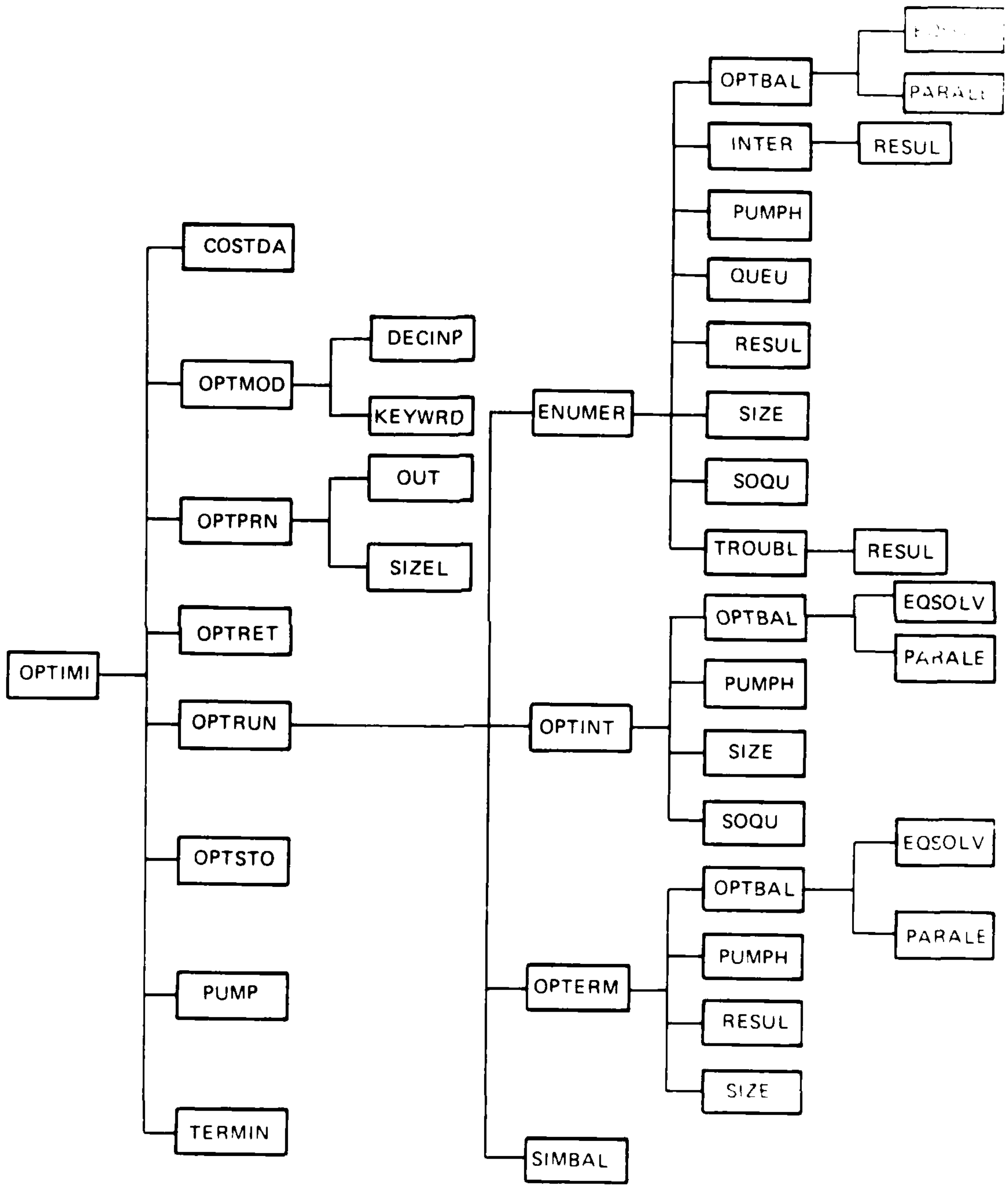

Figure 28-16. Optimization routine

OPTMOD - Called when the user has selected MODIFY OPT. DATA option from the optimization menu in OPTIMI. OPTMOD handles entering of the optimization keywords and numerical data. Also, checks to see that entered data are valid.

OPTPRN - When user chooses to print the optimization data, OPTPRN is called from the subroutine OPTIMI. It displays the group assignments with pipes in each group, the price functions, size assignments, loading patterns, pump efficiency and time running, coefficients for cleaning, pressure tolerance, and cost tolerance.

OPTRET - Called from subroutine OPTIMI, OPTRET retrieves the optimization data from a file created with OPTSTO.

OPTRUN - Called from OPTIMI when a system is to be optimized, OPTRUN's purpose is to call the subroutines OPTINT, ENUMER, and OPTERM to accomplish the optimization. OPTRUN will also call SIMBAL if the system has not yet been balanced.

OPTSTO - Called from subroutine OPTIMI, stores the optimization parameters on a user-selected file. Parameters include number of loading patterns, number of groups, pressure tolerance, cost multiplier, minimum pressure, percent time running of pump, percent efficiency of pump, pipe sizes in group, number of sizes in group, and the Hazen-Williams coefficient for cleaned/lined pipes.

OUT - Called from OPTPRN, OUT places the user link number of the links with internal link numbers, IL, into the output string as the L^{th} entry.

PUMP - Called from subroutine OPTIMI, finds zones within a network that are fed by a single pump and do not have a constant head node.

PUMPH - Called from subroutines OPTINT, ENUMER, and OPTERM, PUMPH shifts the pressure level in zones as determined in subroutine PUMP such that the lowest pressure is equal to zero.

QUEU - Called from subroutine ENUMER, tests a size combination against combinations that were previously tested and failed to meet the pressure requirements.

RESUL - Called from OPTERM and TROUBL, RESUL puts the size of each group into the output string, OUTP.

SIZE - Assigns the proper sizes to the array, DI, for each pipe to be sized, in accordance with the size numbers stored in array ICS. Called from OPTINT, ENUMER, and OPTERM.

SIZEL - Called from OPTPRN, SIZEL assigns all sizes in one group to string OUTP.

SOQU - Called from OPTINT and ENUMER, tests whether the combination ICS is Pareto Optimal; if it is, SOQU eliminates other combinations previously stored in the solution QUEU which are now no longer Pareto Optimal.

TROUBL - Called from ENUMER to tell the user that a combination has failed due to a particular pump.

e. Extended Period Simulation Subroutines (Figure 28-17).

LOAD - Called by TIMSIM to add fire flows to water outputs at nodes that were assigned fires in subroutine TIMEIN and to multiply water uses at nodes by their relative loading factors.

LOWP - Called from TIMSIM at the end of a time step to record the lowest pressure in the system and the node at which the lowest pressure occurs.

PIPEX - Called by TIMSIM to exclude links from an extended period simulation by assigning characteristic pipe coefficients of 1E10 and entries in the coefficient matrix of 1E-10 to those links that are to be excluded.

PUMPCO - Called by TIMSIM to turn pumps on or off depending on time control or pressure control. Pressure control will override time control. Pumps that are turned on are flagged with a "1" stored in array XL, subscripted with the internal pump number. A "-1" in array XL for a pump link indicates the pump is turned off, and the entry in the coefficient matrix, A, is set to zero.

RETIME - Called by TIMENU to retrieve time simulation data from a file that was created with STOTIM.

STOTIM - Called by TIMENU to store the time simulation data. Data are stored on a name specified by the user as a formatted, sequential-access file opened on device 1. STOTIM stores the duration, time step, number of steps, water use ratio, loading factors, water use patterns, fire flow data, tank data, user link numbers of pipes that are to be excluded, and data for pumps being controlled by time and water level.

STRING - Called by TSOUT to place in a string beginning and ending node numbers of links for which flows are being displayed in TSOUT.

TMPRAR - Called by TIMENU right before and after TIMENU calls TIMSIM. When TIMENU calls TMPRAR before entering TIMSIM, TMPRAR assigns water uses and tank node elevations to temporary variables and converts variables UPL, XLOL, HEON, and HEOF to hydraulic heads.

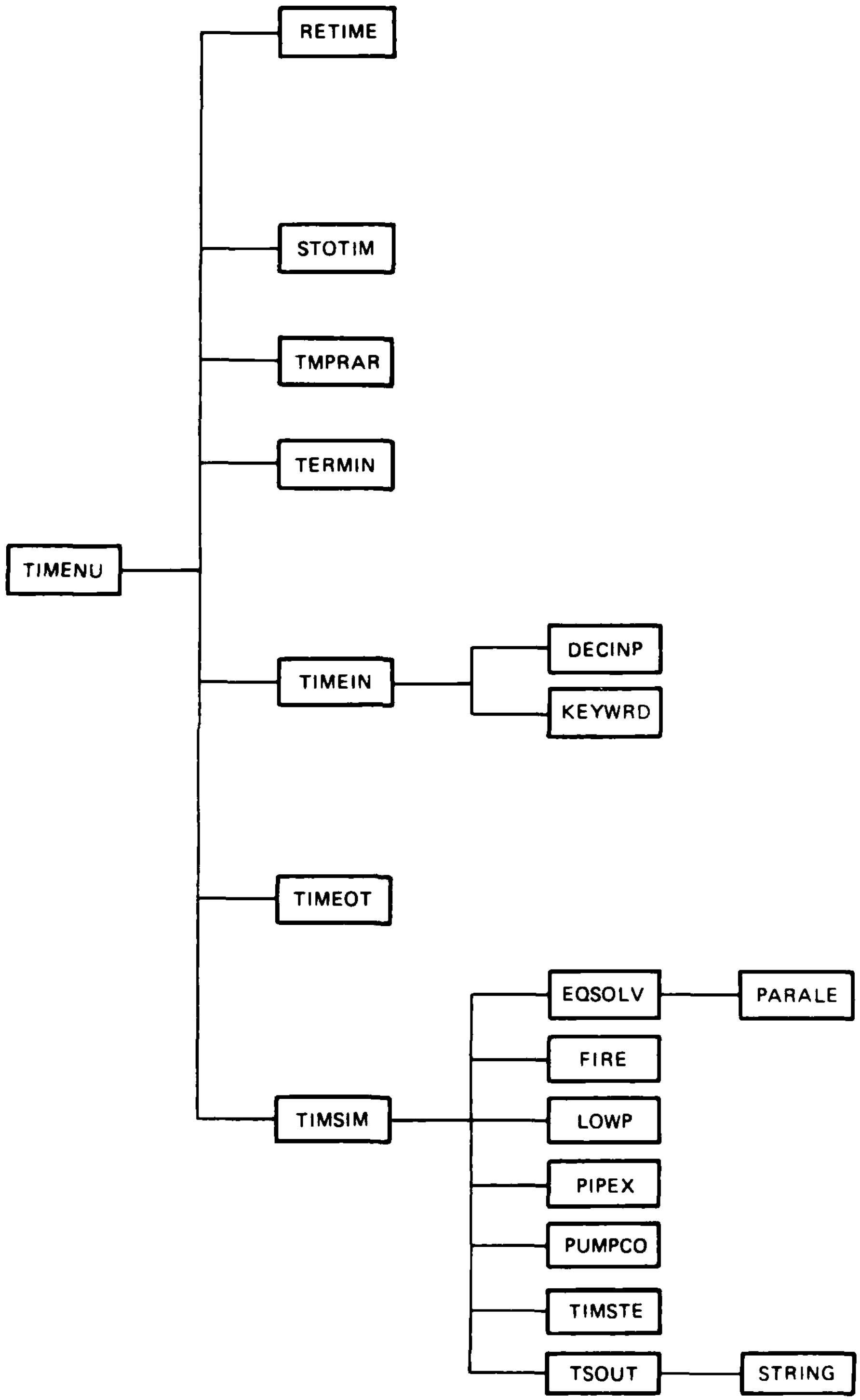

Figure 28-17. Extended period simulation routine

After returning from TIMSIM, TMPRAR assigns the temporary variables back to the original water uses and tank node elevations so steady-state simulation will give some results.

TIMEIN - Called by TIMENU when entering time simulation data to display keyword prompt, read in the time input string, analyze the input string, and make assignments to time variables based on the keyword.

TIMENU - Called from the main program, WADISO, when a time simulation is to be executed. TIMENU displays the menu for time simulation operations and transfers program control to the appropriate subroutine based on the option chosen by the user.

TIMEOT - Called from TIMENU to print the time simulation data. TIMEOT prints simulation data, time step size, number of time steps, ratio of outputs from simulation, tank data, fire data, links out of service, and node usage.

TIMSIM - Called from TIMENU to carry out calculations involved with the extended period simulation. TIMSIM varies tank water levels over time, multiplies water uses by loading factors based on the time step, controls running of pumps, and increments the time of the simulation.

TIMSTE - Called by TIMENU to assign the variable time step, DT, based on a ratio between the largest absolute change in flow into or out of tanks between the previous and current time step and the maximum flow into or out of tanks for the current time step.

TSOUT - Called by TIMSIM to display tank water levels in feet for nodes which are tanks, pressures in pounds per square inch for other nodes, and flows through links in gallons per minute for those nodes and links which the user has specified in TIMEIN. Output is given at the end of each time step.

28-37. Definitions of Variables. This paragraph defines variables used in the WADISO program. They are presented in alphabetical order.

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
A(IA)	/PIPES/	Entry in coefficient matrix.	
A	RESUL	Fractional part of SI.	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
ART(20)	/TIME/	Tank Area. ART(1)=1000 indicates first tank entered has an area of 1,000 square feet.	sq ft
BESTP	/REALS/	Lowest pressure in best combination.	psi
BNS	TSOUT	String containing beginning user node number of link assigned for printout.	
COST(25,12)	/COST/	Price per linear foot. COST(3,1)=10.8 indicates 3rd size in price function 1 is $10.8/foot.	$/ft
CP(PNL)	/PIPES/	Characteristic pipe coefficient or pump indicator.	
C3	EQSOLV INPDAT SIMBAL TIMSIM	Conversion factor from gallons per minute to cubic feet per second (448.831).	gpm/cfs
C4	EQSOLV	Sum of absolute head adjustments for previous iteration	ft
C8	/REALS/	Cost of best combination.	$
C9	OPTINT	Cost of latest combination.	$
D	EQSOLV	Flow rate.	cfs
DDO(20)	TIMSIM TIMSTE	Flow rate into or out of tanks from previous time step.	cfs
DECL	OPTINT	Equivalent pipe diameter in case of cleaning.	ft
DMIN	OPTINT	Smallest equivalent pipe diameter in group for cleaning.	ft

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
DI(PNL)	/PIPES/	Pipe diameter or coefficient of linear term in pump head curve. Subscripted with internal link number after compressing, user link number before compressing. DI(3)=1 indicates link with internal number of 3 has a diameter of 1 foot.	ft
DIFF	PRNINP	Difference between hydraulic grade line and node elevation for tanks.	ft
DM	TIMSTE	Maximum inflow or outflow in tanks in an extended period simulation.	cfs
DM(5,PNL)	/ARRAYS/	Output for loading in optimization. First subscript is loading number; second is internal node number. DM(2,5)=100 means node with an internal number of 5 and loading pattern of 1 has been assigned an output of 100 gallons per minute.	gpm
DO(PNL)	/NODES/	Water use in simulation or tank water level. Subscript is internal node number after compressing, user node number before compressing. DO(3)=100 after compressing indicates node with internal number of 3 is assigned an output of 100 gallons per minute.	gpm
DO(20)	TIMSIM TIMSTE	Flow rate into or out of tanks for current time step.	cfs

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
DOTMP(PNL)	TIMENU TIMSIM TMPRAR	Temporary storage for water use at each node. DOTMP(1)= 100 indicates water use at node with internal number of 1 is 100 cubic feet per second.	cfs
DT	TIMSIM TIMSTE	Variable time step.	min
D1	PRNOUT	Flow through pump.	cfs
EF(PNL)	/ARRAYS/	Pump efficiency. Subscript is internal link number.	%
EL(PNL)	/NODES/	Node elevation. Subscript is user's node number before compressing, internal node number after.	ft
ELE	PRNOUT	Node elevation.	ft
ELTMP(PNL)	TIMENU TIMSIM TMPRAR	Temporary storage for elevation of variable level tank. ELTMP(1)=100 indicates variable level tank with greatest area has an elevation of 100 feet.	ft
ENCO	/COST/	Unit price of energy.	$/kwh
ENDTM	TIMSIM TIMSTE	Remainder of total time, TOT, divided by TSLF*60.	min
ENS	TSOUT	String containing ending user node number of link assigned for printout.	
FAC	OPTINT, OPTRUN	Multiplier for conversion of annual cost to present worth.	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
FF(5)	/TIME/	Fire flow in time simulation FF(1)=100 indicates fire flow for the first fire entered is 100 cubic feet per second.	cfs
FLAC	/ACCU/	Accuracy to which flow will be computed to, when balancing a system with subroutine EQSOLV.	gpm
G(PNL)	/NODES/	Right-hand side of continuity equation. Subscript is internal node number.	cfs
HC	TIMSTE	Hydraulic grade line at node controlling where pump turns on or off, or when tank becomes connected or disconnected.	ft
HDE	TIMSTE	Hydraulic grade line, from previous time step, controlling pump, PRV, or tank.	ft
HE(PNL)	/NODES/	Total hydraulic head. Subscript is user node number before compressing and internal node number after compressing. HE(2)=100 after compressing indicates node with internal number of 3 has a total hydraulic head of 100 feet.	ft
HEOF(20)	/TIME/	Water level when pump turns off.	ft
HEON(20)	/TIME/	Water level when pump turns on.	ft
HETI(20)	/TIME/	Initial tank water level HETI(1)=100 indicates first tank entered has an initial water level of 100 feet.	ft

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
HSET	EQSOLV	Hydraulic grade line below PRV.	ft
HW(PNL)	/PIPES/	Hazen-Williams coefficient HW(3)=120 indicates link internal number of 3 has a coefficient of 120.	
HWCC	/REALS/	Hazen-Williams coefficient for cleaned/lined pipes.	
HWMA	/ACCU/	Default value of Hazen-Williams coefficient.	
HO(3)	INPDAT	Temporary array for pump head.	ft
H1	PRNOUT TIMSIM	Pressure head and head differential in link.	ft
H2,H3	INPDAT	Temporary variables.	ft
I	Several	Do loop counter.	
IA	Parameter	Dimension on array A(IA).	
IB	EQSOLV	Column number of entry I2 on line I.	
IB	INPDAT	Temporary storage for IBI array.	
IBE(PNL)	/TOPOL/	User number of beginning nodes. After node data have been compressed, the subscript is the internal link number. IBE(4)=121 indicates beginning node of internal link number 4 has a user number of 121.	
IBEG	TIMEIN	Beginning time step of usage.	
IBEG	TIMEIN	Beginning node on range.	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
IBI(PNL)	/TOPOL/	Internal beginning node numbers. Subscript is internal link number. IBI(3)=10 indicates link with internal number 3 has beginning internal node 3.	
IBS(15)	/SOLUT/	Portion of array ICS containing the best combinations. IBS(1)=3 indicates the third size in in group 1.	
IB1	SIMBAL	Internal beginning node number of link I.	
IC	INPCST	Temporary storage for price function.	
IC	SOQU	Flag: 1 indicates that a previous entry was removed.	
ICA	OPTPRN	Indicator of price functions used in the optimization.	
ICATE(PNL)	/INTEGR/	Array containing price function assignments. Subscript is internal link number. ICATE(2)=1 indicates pipe with second internal number is assigned to first price function.	
ICL	/ACCU/	Maximum number of iterations.	
ICNT	OPTPRN	ICNT=1 indicates printing of pump efficiency and time running.	
ICOM	ENUMER	Number of combination being tested.	
ICPE	/TIME/	Number of numeric values following keyword EXCL.	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
ICS(15)	OPTINT ENUMER	Combination array for sizes. ICS(3)=2 indicates the second size in group 3.	
IDF(5)	/TIME/	Duration time step of fire. IDF(2)=1 indicates second fire entered has a duration of 1 time step.	
IDTL	/TIME/	Flag: 1 indicates detailed printing of time steps is on. 0 indicates no detailed printing.	
IE	INPDAT	Temporary variable to store one element of IEI array.	
IE	EQSOLV SIMBAL	Temporary storage for element of G array.	
IEN(PNL)	/TOPOL/	User number of ending nodes. IEN(5)=33 indicates ending node of internal link 5 has a user's number of 33.	
IEND	TIMEIN	Ending time step of usage.	
IEND	TIMEIN	End node on range.	
IEI(PNL)	/TOPOL/	Internal ending node numbers. Subscript is internal link number. IEI(3)=9 indicates link with internal number 3 has ending node with internal number 9.	
IE1	SIMBAL	Internal node number of link I. (Column number in matrix.)	
IEX	TIMEIN	User node or tank number.	
IEXP	TIMEIN	User pipe number to be excluded.	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
II	TIMEIN	Temporary variable, first subscript of XLOF.	
IF	OPTPRN	Position of price function in ICATE, starting at position IL.	
IFLAG	ENUMER	Flag: 1 indicates that pressure for a particular combination has not been calculated.	
IFLAG	OPTINT OPTRUN	Flag: 1 indicates error was encountered in OPTINT and tells OPTRUN to return to optimization menu. 0 indicates no error.	
IFLG	RETDAT INPDAT SIMRET	Flag: 1, return is made to input prompt following retrieving of data, instead of simulation menu.	
IFLGG	STODAT	Temporary for O(4), the flag indicating setup of sparse matrix.	
IFOP	EQSOLV OPTBAL SIMBAL TIMSIM	Flag: 1 indicates system is to be balanced for optimization. 0 indicates system is to be balanced for steady-state simulation. -1 indicates system is to be balanced for extended period simulation. 999 indicates system cannot be balanced for extended period simulation.	
IFS(100,15)	ENUMER OPTINT	Array containing size combinations which failed to meet pressure requirements. IFS(3,5)=4 indicates third combination in fifth group is the fourth size.	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
IF1	OPTINT	Flag: 0 indicates not all groups at minimum size. 1 indicates all groups at minimum size.	
IF2	OPTINT	Flag: 0 indicates minimum pressure less than zero; 1, larger than or equal to zero.	
IF3	OPTINT	Flag: 0 indicates minimum pressure larger than or equal to the pressure tolerance; 1, less than pressure tolerance.	
IG	OPTMOD	Numeric value that is part of keyword (group number).	
IGR	/INTEGR/	Number of groups.	
IGROU(PNL)	/INTEGR/	Array containing group assignments. Subscript is internal link number. IGROU(3)=2 indicates pipe with internal number of 3 is assigned to group 2.	
II	STODAT RETDAT	Do loop counter.	
IL	OPTMOD	Temporary storage for II.	
ILC	FIRE LOWP TIMSIM TIMSTE	Counter of time steps for loading patterns.	
ILF	TIMSIM	Time step of loading factor assigned when viewing flows and pressures at a time step.	
ILILI	SIMBAL	Maximum number of entries per matrix line.	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
ILP(57)	LOWP TIMSIM	Internal node with lowest pressure at end of time step ILP(3)=7 indicates node with internal number of 7 had the lowest pressure at end of time step 3.	
IN	ERROR	Sum of IN1, IN2, and IN3.	
INCL	TIMEIN	User link number to include.	
INO(PNL)	/TOPOL/	User node number. Subscript is internal node number.	
INOD	TIMEIN	User node or tank number.	
INTANK(20)	TIMEIN	Flag: 1 indicates pump is controlled by tank level.	
IN1,IN2, IN3	ERROR	Positions of keywords in test strings KEY1, KEY2, and KEY3.	
INUM	TIMEIN	Number of values entered with keyword USAG.	
IP	DECINP INPDAT	Position of period in ST.	
IP	PRNOUT	Page number.	
IP	SIZE	Link number of element to be cleaned.	
IPAT(PNL)	/TIME/	Use pattern. IPAT(2)=5 indicates second node is assigned to use pattern 5.	
IPE	/PRINT/	Print control; 1 indicates responses will be echoed.	
IPEX(15)	/TIME/	User link number to exclude. IPEX(2)=9 indicates user link 9 was the second link to be excluded.	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
IPI(LNL)	/TOPOL/	User number of links. Subscript is internal link number. IPI(3)=5 indicates user link 5 has internal number 3.	
IPK1	INPCST	Position of KTYPE in IKEY1.	
IPM	/PRINT/	Print control; 1 indicates menus are to be printed.	
IPP	/PRINT/	Print control; 1 indicates prompts are to be printed.	
IPR	/TIME/	Flag: 1 indicates printing of flows and pressures at the beginning and end of each time step.	
IPRS	TIMSTE	1 indicates PRV in system.	
IPRV	TSOUT	Number of PRVs assigned for printout in an extended period simulation.	
IPUMP	TIMEIN	User link number of pump (temporary storage).	
IP1	PRNOUT	User link number.	
IQ	QUEU	Flag: 0, pressure distribution will need to be evaluated; 1, pressure computations can be skipped.	
ISCOT	KEYWRD	Flag: 1, 2, 3, or 4 tells KEYWRD to display simulation, cost, optimization, or time keywords, respectively. 10, 20, 30, or 40 tells KEYWRD to display keyword formats for simulation, cost, optimization, or time, respectively.	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
ISP(14)	/ARRAYS/	Pattern number that caused minimum pressure.	
ISQ	/INTEGR/	Number of combinations in array ISS.	
ISS(20,15)	/SOLUT/	Pareto Optimal combination array for sizes. First subscript refers to combination number; second subscript refers to group number. ISS(2,3)=4 indicates fourth size of group 3 is combination 2.	
ISTP	TIMEIN	Flag: 1 indicates default time steps and duration will be used.	
ISUB	LOWP	Subscript for arrays XLP and ILP. ISUB-ILC at the end of each time step and ISUB=2*ILC-1 at the beginning of each time step.	
IT	PRNOUT	User node number and temporary variable.	
IT	SIMBAL	Temporary storage for IE1 variable.	
ITC	TIMSIM	Counter of time steps to serve as subscript in array PUST to record pump status. After simulation, used as time step when tank levels change.	
ITF(5)	/TIME/	Starting time step of fire. ITF(2)=3 indicates starting time of second fire is third time step.	
ITFL	TIMSIM TSOUT	Flag: 0 indicates all tanks in system have drained.	
ITFL1	TIMSIM TSOUT	Flag: 0 indicates all tanks in system have drained.	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
ITN	TIMSIM TIMSTE	Number of tanks defined for an extended period simulation.	
ITNC	TIMSTE	Number of constant head tanks defined for an extended period simulation.	
ITNK	TIMSTE	Flag: 1 indicates pump is controlled by tank water level. 0 indicates pump is not controlled by tank node.	
ITN	TIMSIM TIMSTE	Number of tanks with variable tank levels.	
IUSE	TIMEIN	Use pattern.	
IVAL	TIMEIN	Difference between beginning and ending time step plus one.	
IW	EQSOLV	Number of node with pressure P8.	
IWO	EQSOLV	Number of node with pressure P88.	
IO	OPTINT	Do loop counter.	
IO	SOQU	Temporary variable, entry number in queue.	
IOO	OPTINT	Counter used as second sub-script in TC and SI arrays.	
IOO	SOQU	Number of entries in queue.	
I1	SIMBAL	Link number, entry number.	
I1	EQSOLV	Link number, node number.	
I2	EQSOLV SIMBAL	Entry number on line I of matrix.	
I2	OPTINT	Temporary storage (size number).	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
I3	EQSOLV SIMBAL	Do loop counter.	
I3M	EQSOLV	Node number with maximum head adjustment.	
I4	EQSOLV	Temporary storage for for element of N2 array.	
I4M	EQSOLV	Node number with maximum flow imbalance.	
I5	EQSOLV SIMBAL	Running nonzero entry number on matrix line IB1.	
I6	EQSOLV	Iteration counter.	
I6,I7	SIMBAL	Temporary variables.	
I66	TIMSIM	Number of times program attempts to balance a system that will not converge in an extended period simulation. Two times is the limit, with ICL iterations performed each time.	
I8	SIMBAL	Link number of element I7.	
J	INPDAT	Position of comma or blank space in string ST.	
J	PRNINP	Storage for user's ending node.	
J	several	Do loop control variable.	
JMAX	TIMEIN	Number of pipes to exclude.	
JOB	/JOB/	Job name.	
J0	INPDAT	Flag: 0 indicates no supply point.	
J0	OPTINT	Do loop counter.	
J0	PUMP	Link number.	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
J1	JJ	Location of T1 in ST.	
J2	JJ	Location of T2 in ST.	
K	INPDAT	Collating weight of character in string ST.	
KC	/COST/	Number of cost functions.	
KS	/COST/	Number of SIZES.	
KEY	OPTDAT	Optimization keywords.	
KEY1,KEY2, KEY3	INPDAT, ERROR	Strings containing current simulation keywords.	
KTYPE	DECINP,INPDAT, INPCST,OPTMOD TIMEIN	Keyword.	
KTYPF	DECINP,INPCST, OPTMOD,TIMEIN	Second keyword in input string.	
KW	TIMEIN	String containing available time keywords.	
K0	PRNINP	Temporary variable.	
K0	OPTINT QUEU	Number of combinations in IFS.	
K0, K1	OPTMOD	Internal node number and internal link number.	
K1	DECINP INPDAT	Collating weight of character.	
L	DECINP	Number of numeric values read in input string.	
L	INPDAT	Number of numeric values read plus one.	
L	PRNINP	User link number.	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
LIST(5)	TIMEOT	Header for printing of loading patterns. LIST(2)=3 indicates second pattern used is number 3.	
LL	INPCST	Added to KS to update sizes.	
LNL	Parameter	First subscript on arrays N1 and N2. (Maximum number of links and maximum number of nodes allowed.)	
LPAT(5)	/TIME/	Loading pattern flag. LPAT(2)=1 indicates second loading pattern is used. LPAT(1)=0 indicates first loading pattern has not been used.	
LTF	TIMEIN	Ending time step of fire.	
LTP	TIMEIN	Ending time step of pump running.	
LO	PRNOUT	Line counter.	
M(PNL)	/MATRI/	Number of nonzero entries on matrix line.	
M	RESUL	Flag: 1 indicates that rounding is to take place.	
MM	DECINP INPDAT	Flag: 0 indicates character to left of decimal point; 1, character to right of decimal point.	
MNL	Parameter	Limit of second subscript on arrays N1 and N2.	
MOLD	OPTINT SOQU	Pattern number of pattern combination with lowest pressure.	
MUNU	/INTEGR/	Number of loading patterns.	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
MO	OPTINT EQSOLV SIMBOL	Pattern and group number.	
N	ENUMER	Number of combinations to be tested.	
N	RESUL	Remaining digits to be assigned.	
NBA	TMPRAR	Flag: NBA=1 before entering TIMSIM and NBA=-1 after TIMSIM.	
NERR	INPDAT ERROR	Number of input error.	
NF	RETIME STOTIM	Number of fires in system.	
NFIRE(5)	/TIME/	User node supplying fire flow. NFIRE(1)=6 indicates user node 6 is supplying the first fire entered.	
NOLI(10)	/TIME/	User link or node number for which data are to be displayed in the extended period simulation. NUSR(1)=5 indicates first node or link entered for time output is number 5.	
NOPU(20)	/TIME/	User node number that controls pump. NOPU(1)=10 indicates first pump entered is controlled by user node number 10.	
NOTANK	TIMEIN	Tank node.	
NP	TIMEOT STOTIM RETIME	Number of loading patterns in the extended period simulation.	
NPATT	TIMEIN	Use pattern.	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
NPUC	RETIME STOTIM	Number of pumps controlled in an extended period simulation.	
NPUMP(20)	/TIME/	User link number of pump. NPUMP(1)=30 indicates first pump entered has a user link number of 30.	
NS(15)	/ARRAYS/	Number of sizes in group.	
NSTEP	/TIME/	Number of time steps.	
NTANK(20)	/TIME/	User tank number. NTANK(2)=15 indicates second tank entered has a user node number of 15.	
NTN	RETIME STOTIM	Number of tanks in system.	
NTM	TIMEIN	Temporary storage for tank number.	
NUM	DECINP INPDAT	String containing numbers 1 through 9. Used as an internal collating sequence.	
NUM	TIMSIM	Number entered which corresponds to time step to view.	
NUMB	RESUL OUT SIZEL	String containing numbers 0 through 9. Used as an internal collating sequence.	
NUSR(10)	/TIME/	Character array storing NODE for nodes and LINK for links that are to be printed out is subroutine TSOUT. NOLI(1)=NODE indicates first node entered for time simulation output is a node.	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
NW	TIMEIN	Character string containing numbers 0 through 9 to test against leading character of input string.	
NY	/COST/	Number of years.	
N1(LNL,MNL)	/MATRI/	Line number. First subscript is line number in matrix (internal node number); second is entry number of nonzero coefficients on line.	
N2(LNL,MNL)	/MATRI/	Column number. Subscripts are the same as for N1.	
N3(PNL)	/INTEGR/	Array containing zone assignments.	
N4(PNL)	PUMP	Array flagging nodes checked for zone with a 1.	
O(15)	/NODES/	O(1) - Number of links O(2) - Number of nodes O(3) - Total link counter O(4) - Flag: 1 if sparse matrix accomplished O(9) - Flag: 0 if system not balanced; 3 if system is balanced O(10)- Flag for PRVs and/or check valves and second time through iteration O(12)- Flag: -3 indicates last pass through EQSOLV routine O(14) Flag: 1 indicates presence of dead-end zones served by pump	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
OUTP	OPTINT,OUT OPTERM,ENUMER, SIZEL, RESUL, TROUBL	Output string.	
O0	SIMSTO SIMRET	Flag indicating file was created as a backup.	
O1	SIMSTO SIMRET	Number of links.	
O2	SIMSTO SIMRET	Number of nodes.	
O4	EQSOLV	Assigned to 0.1 and used for comparison with X8.	
PAT	OPTRUN OPTINT OPTERM	Loading pattern that generated lowest pressure.	
PATT	OPTINT	String, flagging patterns which failed with character of collating weight 1.	
PNL	Parameter	Highest allowable node and link number.	
POLD	OPTINT SOQU	Lowest pressure in all patterns.	psi
POS	RESUL SIZEL	Position of number in output string, OUTP.	
PRAC	/ACCU/	Accuracy to which pressure distribution will be computed when balancing a system.	psi
PRVS	TSOUT	String containing state of PRV (e.g., CLOSED, OPEN, or ACTIVE).	
PSET	INPDAT	Pressure setting for PRV.	psi

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
PT(5,PNL)	/ARRAYS/	Percent time running of pump. First subscript is loading number, second is internal link number. PT(2,101)=0.1 indicates pump with internal link number 101 has a percent efficiency of 0.1 under loading pattern 2.	
PUBE	/NAME/	Initial status of pump. PUBE="ON" if pump is initially on and PUBE="OFF" if pump is initially off.	
PUST(20,114)	TIMSIM PUMPCO	Status of pump at the beginning and end of each time step over the extended period simulation. PUST(2,1)=-1 indicates second pump entered is off at beginning of first time step. PUST(2,1)=1 indicates second pump entered is on at the beginning of first time step.	
P8	ENUMER EQSOLV OPTBAL OPTERM OPTINT SIMBAL	Minimum pressure in iteration.	psi
P8M	PUMPH	Minimum pressure in zone.	psi
P88	ENUMER EQSOLV OPTBAL OPTERM OPTINT	Minimum pressure in previous iteration.	psi
P9	PRNOUT	Pump power.	hp
RATIO	/TIME/	Value by which outputs are multiplied.	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
RES1	TIMSIM	Character string containing "0123456789" to check if user's response is a number.	
RES2	TIMSIM	Character string containing NR to check if user's response is an "N" or "R."	
Q0	INPDAT	Temporary array for pump discharge.	cfs
Q0,Q1	SIZE	Temporary variables for Hazen-Williams coefficient.	
Q2,Q3	INPDAT	Temporary variables for determining pump characteristic curve.	cfs
Q4,Q5	INPDAT	Temporary variables for determining pump characteristic curve.	cfs**2
R1	INPDAT	Link number.	
R2	EQSOLV	Temporary variable (head).	ft
R3	EQSOLV	Sum of absolute head adjustments.	ft
R3	INPDAT	Temporary storage for Hazen-williams coefficient.	
R3M	EQSOLV	Maximum head adjustment.	ft
R4M	EQSOLV	Maximum flow imbalance.	cfs
R22	/REALS/	Pressure tolerance.	psi
R23	/REALS/	Cost tolerance, multiplier.	
R8	EQSOLV	Multiplying factor.	
S(PNL)	/NODES/	Diagonal member of matrix/ total hydraulic head/net outflow at node. Subscript is internal node number.	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
SCO(14)	/ARRAYS/	Total system cost of Pareto Optimal solutions. Subscript is solution number.	$
SPR(14)	/ARRAYS/	Minimum pressure for the Pareto Optimal solutions. Subscript is solution number.	psi
SI(15,10)	/ARRAYS/	Pipe sizes in group. First subscript is group number, second is number of size in group. SI(2,3)=12 indicates third size in group 2 is 12 inches.	in.
SIZ(25)	/COST/	Pipe sizes (e.g., SIZ(6)= 12 in. indicates that the sixth pipe size is 12 inches).	
ISS(20,15)	/CHARS/	Array containing the combinations of the Pareto Optimal solutions. First subscript is combination number, second is group number.	
ST	INPDAT,DECINP, OPTMOD,INPCST	User's input string.	
STRNG	TSOUT STRING	String containing node numbers of links assigned for printout. STRNG(1:2)=9 indicates node number 9 is in first two positions of string.	
S1	EQSOLV	Head drop along link.	ft
TAH(20,57)	TIMSIM	Tank level as a function of time. TAH(1,1)=100 indicates first tank entered has a water level of 100 feet for first time step.	ft
TB1	TIMSTE	Smallest "on" time for pumps or closed time for pipes greater than TOT/60.	hr

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
TC(15,10)	/ARRAYS/	Total cost of a size in a group. TC(3,2)= 76300 indicates size 2 in group 3 has a cost of $76,300.	$
TEB(16,7)	/TIME/	Time when pipe closes (exclusion begins). TEB(7,5)=7.3 indicates that the seventh excluded pipe entered closes for fifth time at time 7.3 hours.	hr
TEE(16,7)	/TIME/	Time when pipe opens (exclusion ends). TEE(3,1)= 4.5 indicates third excluded pipe entered first opens at time 4.5 hours.	hr
TE1	TIMSTE	Smallest "off" time for pumps or open time for pipes greater than TOT/60.	hr
TMAX	/TIME/	Total time.	hr
TM1	TSOUT	Temporary storage for an element in array NOLI. TM1= NOLI(2) indicates second word in array NOLI is temporarily stored in TM1.	
TM2	TSOUT	Temporary storage for an element in array NUSR. TM1=NUSR(2) indicates second number in array NUSR is temporarily stored in TM2.	
TM3	TSOUT	Temporary storage for an element in array UNIT. TM1=UNIT(2) indicates second word in array UNIT is temporarily stored in TM2.	
TOS	TSOUT	String containing the characters "TO."	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
TOT	FIRE PIPEX TIMSIM TIMSTE	Elapsed time of extended period simulation.	min
TP	OPTINT, OPTBAL SIMBAL, EQSOLV	Pump energy for all combinations.	lb-ft
TPB(20)	/TIME/	Time when pump turns on. TPB(2)=1 indicates starting time of second pump entered is the hour 1.	
TPE(20)	/TIME/	Ending time of pump running. TPE(2)=3 indicates second fire entered ends at hour 3.	
TPMP	TIMSTE	Smallest of the smallest off and on times for pumps and pipes.	hr
TP0	/REALS/	Pump energy cost (present worth) for largest pipe sizes.	lb-ft/$
TP1	OPTINT	Pump cost (present worth).	$
TP2	/REALS/	Pump cost (present worth) for best combination.	$
TSLF	/TIME/	Step size.	hr/step
TYPE	DECINP INPCST OPTMOD	First keyword from previous entry.	
TYPF	DECINP INPCST OPTMOD	Second keyword from previous entry.	
T0	EQSOLV	Absolute value of head deep along link.	
T2	INPDAT	Assigned to ",".	
T3, T4	INPDAT	Temporary storage for beginning and ending node.	

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
UNIT(10)	/TIME/	Character array storing PSI, FT, or GPM for nodes and links that are to have output displayed in the extended period simulation.	
UPL(20)	/TIME/	Upper tank water elevation. UPL(1)=100 indicates upper water elevation for first tank entered is 100 feet.	ft
VALUE(30)	DECINP INPCST INPDAT OPTMOD TIMEIN	Array of numeric input values.	
VEL	PRNOUT	Velocity in pipe.	ft/sec
W7	SIZE	Equivalent pipe diameter in case of cleaning.	ft
XI	/COST/	Interest rate.	fractions of 1
XL(PNL)	/PIPES/	Pipe length, if XL<100000 PRV, if XL>100000. Check value if XL<Ø. Subscript is internal link number.	ft
XLIST(10)	TSOUT	Array containing flows and pressures of links and nodes assigned for printout.	gpm psi
XLOF(57,5)	/TIME/	Loading factor XLOF(2,3)=1.5 indicates loading factor for second time step, third loading is 1.5.	
XLOL(20)	/TIME/	Lower tank elevation. XLOL(2)=110 indicates lower water elevation for the second tank entered is 110 feet.	ft
XLOW	LOWP	Lowest pressure head at end of time step.	ft

VARIABLE NAME	SUBROUTINE OR /COMMON/	DEFINITION	UNIT
XLP(57)	LOWP TIMSIM	Lowest pressure of all nodes at end of time step. XLP(2)=20 indicates lowest pressure at end of time step 2 is 20 pounds per square inch.	psi
XNO	ENUMER	Percent completeness of job.	%
XP(5,PNL)	/ARRAYS/	Minimum pressure. XP(3,1)=40 indicates third loading on node with internal number of 1 is 40 pounds per square inch.	psi
XSTEP	TIMEIN	Number of time steps.	
X1,X2	OPTINT	Temporary variables.	
X8	EQSOLV	Average correction on node heads.	ft
Y0	EQSOLV	Temporary variable, used in determining A element for pumps.	
Y1	INPDAT	Coefficient of quadratic term of parabola for characteristic pump curve.	
Y1,Y2	EQSOLV PRNOUT TSOUT	Temporary variables for pumps.	
Y2	INPDAT PRNOUT	Coefficient of linear term in the characteristic pump curve.	
Y3	EQSOLV PRNOUT	Temporary variable for pump.	
Y3	INPDAT	Shutoff head in characteristic pump curve equation.	ft
Y4	EQSOLV	Temporary variable for check valves.	

28-38. Changing Array Dimensions. This paragraph describes when to change parameters in the program. When entering large systems or ones with inefficient numbering schemes, one or more of the parameters in the program may need to be increased. Parameters, their definitions, and when they may need to be increased to allocate additional memory are listed below.

PARAMETER	DEFINITION	WHEN TO INCREASE
IA	Subscript on the A array, the entry in the coefficient matrix.	When entering a large system. WADISO will display a message notifying the user to increase the parameter when unable to balance a system of this size.
LNL	First subscript on N1 and N2 arrays.	When entering a system exceeding the maximum allowable number of links. WADISO displays this limit at the beginning of the program run.
MNL	Second subscript on N1 and N2 arrays.	When balancing a large system or one with a wide range of link and node numbers. WADISO will notify the user when it is necessary to increase this parameter.
PNL	Subscript on all link and node arrays.	When entering a node or link number exceeding the maximum allowable link or node number. WADISO displays this limit at the beginning of the program run.

To change any of these parameters, their values can be modified globally in the source code using an editor. The program must then be recompiled.

END
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